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MORTALITY RATES AND MOVEMENT IN THE CHANNEL CATFISH POPULATION OF THE SACRAMENTO VALLEY [1]

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INTRODUCTION

Channel catfish *(Ictalurus punctatus)* were first introduced into the Central Valley of California in 1891. An unauthorized introduction also took place sometime between 1925 and 1930. Each of these introductions occurred in the northern part of the Central Valley, in that major division known as the Sacramento Valley. The approximate north and south boundaries of the Sacramento Valley are the cities of Redding and Stockton, respectively.

The first authentic record of capture of the species was not made until 1942, and from that year until 1950 reports of observations of channel catfish were infrequent. During that period, the sport catfish catch of the Sacramento Valley was dominated by the white catfish *(Ictalurus catus)*. The brown bullhead *(I. nebulosus)* and black bullhead *(I. melas)* were present in the area, but their contribution to the fishery was of minor importance.

About 1950, channel catfish began appearing in substantial numbers in the sport fishery of the lower Sacramento Valley. Although estimates of the total catch were unavailable, it was evident by 1954 from newspaper reports and field observations by California Department of Fish and Game personnel that a channel catfish fishery of major proportions had been established.

The large size of the fish enhanced the popularity of the fishery. Specimens weighing from 5 to 10 pounds were caught frequently, with an occasional individual of 15 to 20 pounds appearing in the catch.

The fishery area is restricted in size and roughly triangular in outline, with Marysville on the Feather River, Colusa on the Sacramento River, and the confluence of the Sacramento and Feather rivers at the apexes (Figure 1). Sutter Bypass, a flood control channel possessing permanent sloughs, traverses the area from Colusa to a point immediately upstream from the mouth of the Feather River. Angling use is greatest along the Bypass sloughs.

An exploratory tagging experiment was undertaken in the spring of 1955 to gather information pertinent to the management of the new fishery. The primary objectives were: (1) to ascertain the movements

[1] Submitted for publication May, 1960. This work was performed as part of Dingell-Johnson Project California F-2-R, "A Study of the Catfish Fishery of California", supported by Federal Aid to Fish Restoration funds.

of the fish; and (2) to obtain reliable estimates of mortality rates within the population. This paper presents the results of the study.

ACKNOWLEDGMENTS

Special thanks are due coworkers Vincent Catania and Ross Waggoner, who assisted with field operations. The authors are indebted to Dr. W. E. Ricker of the Fisheries Research Board of Canada for suggestions on the presentation of the mortality data. The assistance of the Twin Cities Rod and Gun Club in handling the prize drawing for tag returnees is gratefully acknowledged. Cliffa Corson prepared the figures.

TAGGING METHODS

A total of 797 fish was tagged: 199 in the Sacramento River at the mouth of Sacramento Slough, one-half mile upstream from the mouth of the Feather River; 200 in the Sacramento River at the mouth of Butte Creek, five miles downstream from Colusa; 200 in the Feather River about five miles below Marysville; and 198 in the West Cut of Sutter Bypass at the Highway 40A causeway. All tagging was accomplished during April and May, 1955.

The fish were captured by means of fyke nets, as described by Pelgen and McCammon (1955). Nets were fished for four or five days before being raised. Extensive catfish trapping in other California waters has demonstrated that several days of undisturbed fishing are required to produce optimum catches. The condition of all fish was excellent at time of tagging.

The disk-dangler tag was used exclusively. The construction of this tag and the method of attachment on catfish have been described by Pelgen (1954). It is the most reliable tag available for catfish.

Fork length, to the nearest one-tenth of an inch, was recorded for 794 tagged fish. The mean length was 12.1 $\pm$ 0.1 inches, with a range from 6.8 to 22.1 inches. Length frequencies of fish tagged in each of the four areas are shown in Tables A-1 through A-4 of the Appendix. Some size selection was exercised. A minimum tagging length of 7.0 inches fork length was established; however, an oversight resulted in the tagging of one 6.8-inch specimen.

As shown in Table 1, the mean lengths of three of the samples were approximately equal, while the catfish tagged in Sutter Bypass were appreciably larger. An analysis of variance computation demonstrated significant differences between the four means at the 5 percent level ($F = 146.8$; d.f. 3, ∞; $P < 0.05$). A multiple range test (Duncan, 1957) at the 5 percent level, revealed significant differences between all the means except those for fish from Sacramento Slough ($m = 11.1$) and the mouth of Butte Creek ($m = 10.8$). Nonrandom sampling, due to nonrandom distribution of the fish, probably accounts for these differences. The presence of larger catfish in the Bypass is discussed in a subsequent section of this report.

Inasmuch as tag recoveries were dependent upon voluntary returns from individual anglers, several methods of stimulating angler interest were employed. Posters informing the public about the State's catfish tagging program, as described by Pelgen (1954), were distributed throughout the study area at popular fishing spots, fishing resorts, and

TABLE 1
Comparison of Lengths of Channel Catfish Tagged and Returned

Tagging location	Fish tagged			Fish returned		
	Number	Range in fork length (inches)	Mean fork length (inches)	Number	Range in fork length* (inches)	Mean fork length* (inches)
Sacramento Slough	199	6.8–19.2	11.1	53	8.1–17.6	11.2
Butte Creek mouth	200	7.6–18.9	10.8	58	8.0–18.9	11.4
Feather River	198	7.7–20.9	11.7	60	8.8–20.9	12.3
Sutter Bypass	197	9.4–22.1	14.9	55	9.5–21.9	15.3
Totals	794	6.8–22.1	12.1	226	8.0–21.9	12.5

* Lengths at time of tagging.

sporting goods stores. The address to which the angler was to mail the tag and recovery information was printed clearly on each tag, and a commendation card bearing a brief history of each fish was sent to every person who returned a tag. Anglers who reported tag recoveries within the first 12 months of the study were eligible for a prize drawing sponsored by the Twin Cities Rod and Gun Club of Yuba City. This drawing consisted of $200 in cash prizes, appropriated to the club by the Sutter County Board of Supervisors from county fine monies.

RESULTS

General

Anglers returned 228 tags (29 percent) over a period of four years, including two from fish that had not been measured at the time of tagging. An additional seven recoveries were made by Department of Fish and Game personnel. The latter recoveries were used for determining fish movements only.

Tag returns are grouped according to the number of months elapsed since the date of tagging, divided into 12-month periods. For example, a fish tagged May 15, 1955, and recaptured April 30, 1958, had been at liberty 35+ months and is therefore assigned to year 3 of recovery. Annual recoveries were: first year, 146; second year, 54; third year, 20; and fourth year, 8 (Table 2; Appendix, Tables A-1, A-2, A-3, A-4).

TABLE 2
Summary of Angler Tag Returns from Channel Catfish in the Lower Sacramento Valley

Tagging area	Number tagged	Tag returns				
		First year	Second year	Third year	Fourth year	Totals
Sacramento Slough	199	33	14	4	2	53
Butte Creek mouth	200	34	20	2	2	58
Feather River	200	33	13	12	4	62
Sutter Bypass	198	46	7	2	0	55
Totals	797	146	54	20	8	228

A chi-square test at the 5 percent level revealed a statistically significant size difference, at time of tagging, between all fish tagged and those from which tags were returned (Table 1). Close inspection of the data disclosed that this difference was a result of: (1) disproportionately fewer returns from fish less than 9.0 inches fork length during the first recovery year, and (2) greater returns than expected for fish over 15.0 inches during the first year. Fish caught during the second, third, and fourth years were not significantly different in size from the original tagged population.

The explanation of the size discrepancies in the first year returns is twofold. First, it is evident that the fish less than 9.0 inches in length were not fully recruited to the fishery during the initial 12 months. This is not surprising when it is recognized that the fishery was directed primarily toward large fish, and the fishing gear was selected accordingly. Tagging mortality or loss of tags in the 7.0-8.9-inch size group is rejected as a possible reason, since fish from this group were returned in proportionate numbers after the first year. Second, the unexpectedly high recovery of fish over 15.0 inches is easily explained. Of 149 fish that were 15.0 inches and over in length, 104 (70 percent) were tagged in Sutter Bypass, where angling pressure was greatest. Thus, their high first-year return is simply a manifestation of a higher rate of exploitation.

Movement of Tagged Fish

During the four years of the study, tag returnees provided sufficient information to determine both the direction and distance traveled by 150 catfish. An additional 59 returns gave enough data to determine the general direction of movement, but no accurate measure of distance. Fifty-four of the latter returns were from Sutter Bypass. Only 26 returns were of no value in determining movements.

The location of angler recaptures during each annual recovery period and for each release point are depicted in Figures 1, 2, 3, and 4. A general understanding of the distinctive characteristics of channel catfish movements in this population can be gathered by relating these data to general knowledge of the fishery and local environmental factors.

Most of the recaptures occurred within a relatively restricted area. Only 29 (13 percent) of the total recoveries were reported from outside the triangular area described by Colusa, Marysville, and the junction of the Sacramento and Feather rivers, and many of these were only a short distance beyond the area boundaries. This is surprising, since three of the tagging locations were in proximity to the edges of the area, and it is known from other channel catfish tagging experiments in North America that the species has a propensity for moving long distances, when the environment is suitable. Although geographical variations in angling intensity undoubtedly influenced recovery locations, it is apparent that there was little tendency toward emigration, either upstream or downstream, from the described area. Admittedly, there is relatively less angling pressure on the Feather River above Marysville than there is below, but this is not true for the Sacramento River above Colusa or below the mouth of the Feather River.

The evidence of a restrained population provided by tag recovery data is supported by the general paucity of angler reports of the

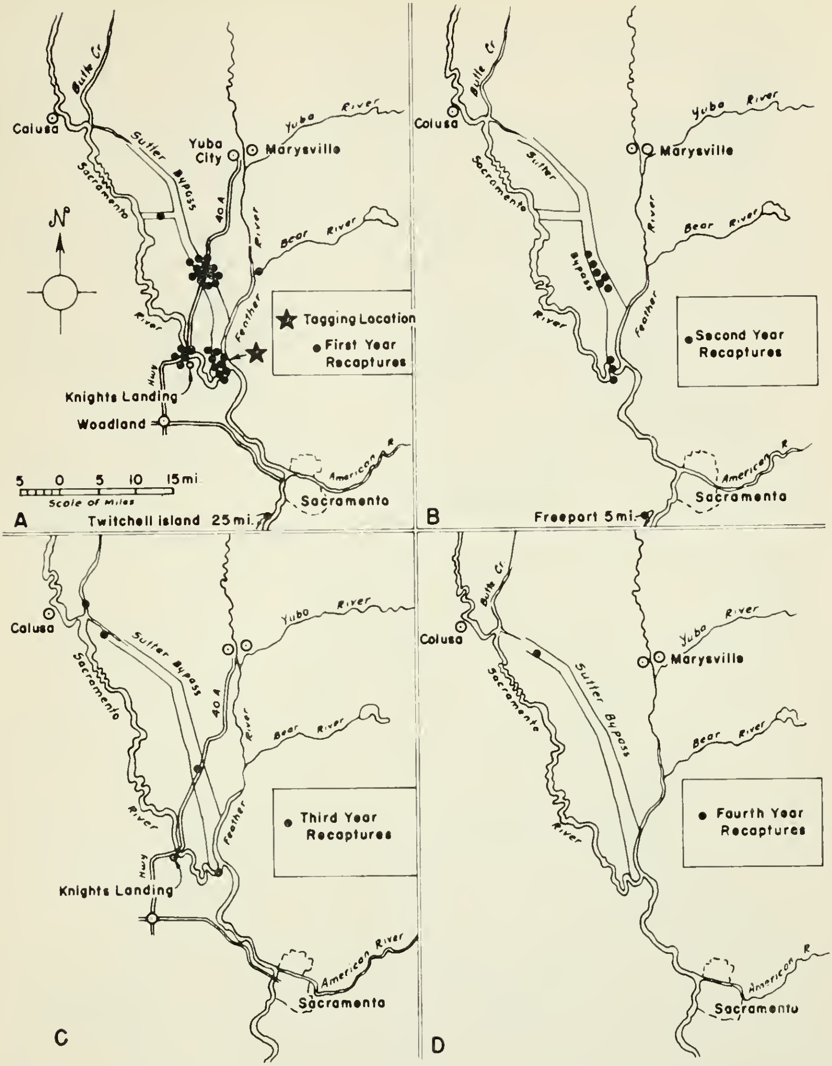

FIGURE 1. Angler recoveries of channel catfish tagged in April 1955, in the Sacramento River at Sacramento Slough. **A,** recaptures during first year; **B,** recaptures during second year; **C,** recaptures during third year; **D,** recaptures during fourth year.

capture of untagged channel catfish in either the Sacramento-San Joaquin Delta region or in the Sacramento River upstream from Colusa.

Although the reasons for a relatively closed population of a nonsedentary fish are not obvious, some light is shed on the problem when their distribution is correlated with relevant data on the environmental qualities of the Delta and the Sacramento River above Colusa. For instance, the completion of Shasta Dam in 1944 has altered the temperature regime of the Sacramento River greatly. Most of the river from the dam downstream is now coldwater habitat. Daily maximum

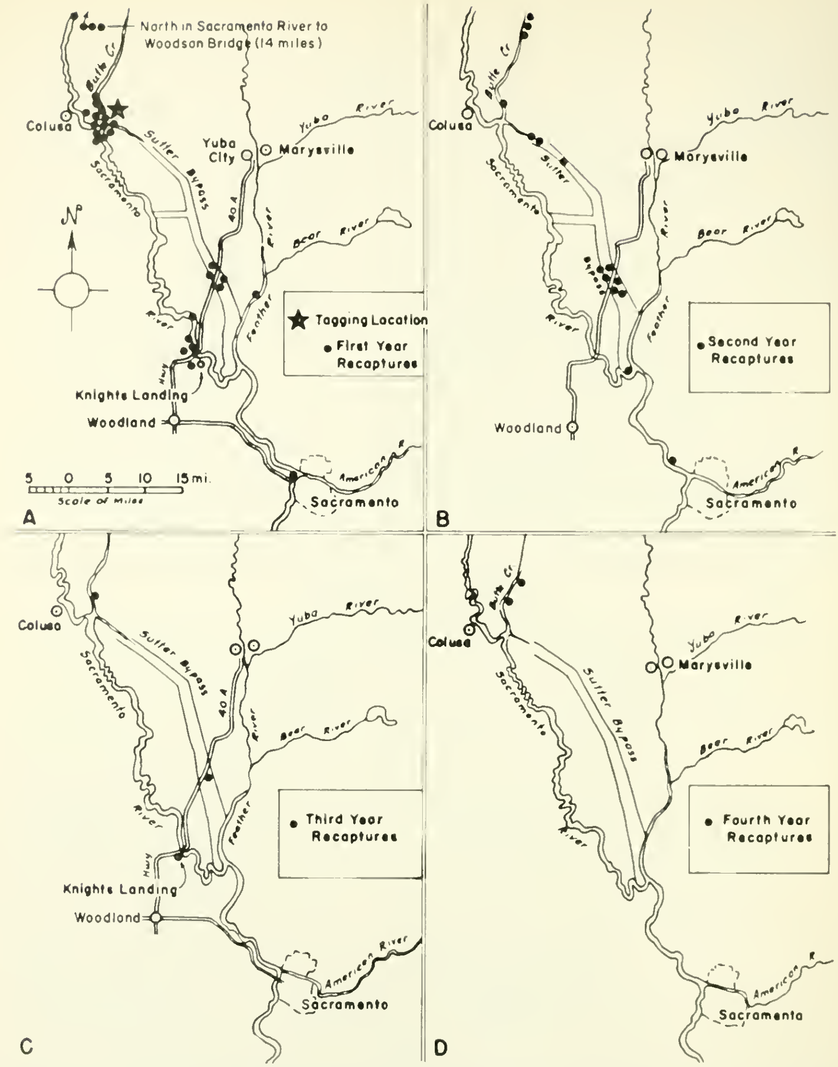

FIGURE 2. Angler recoveries of channel catfish tagged in April 1955, in the Sacramento River at Butte Creek. **A**, recaptures during first year; **B**, recaptures during second year; **C**, recaptures during third year; **D**, recaptures during fourth year.

river temperatures above Hamilton City, about 30 miles above Colusa, have never exceeded 68 degrees F. since power generation commenced (Cope, 1949, 1952). Mean maximum summer temperatures at Colusa and below always exceed 70 degrees F. The channel catfish is a typical warmwater species, preferring summer water temperatures over 70 degrees F. It is not surprising that they shun the cold upper section of the river, despite the apparent suitability of other physical factors.

The lack of movement into the Delta is difficult to comprehend, since the physical environment appears suited to the species. Occasional re-

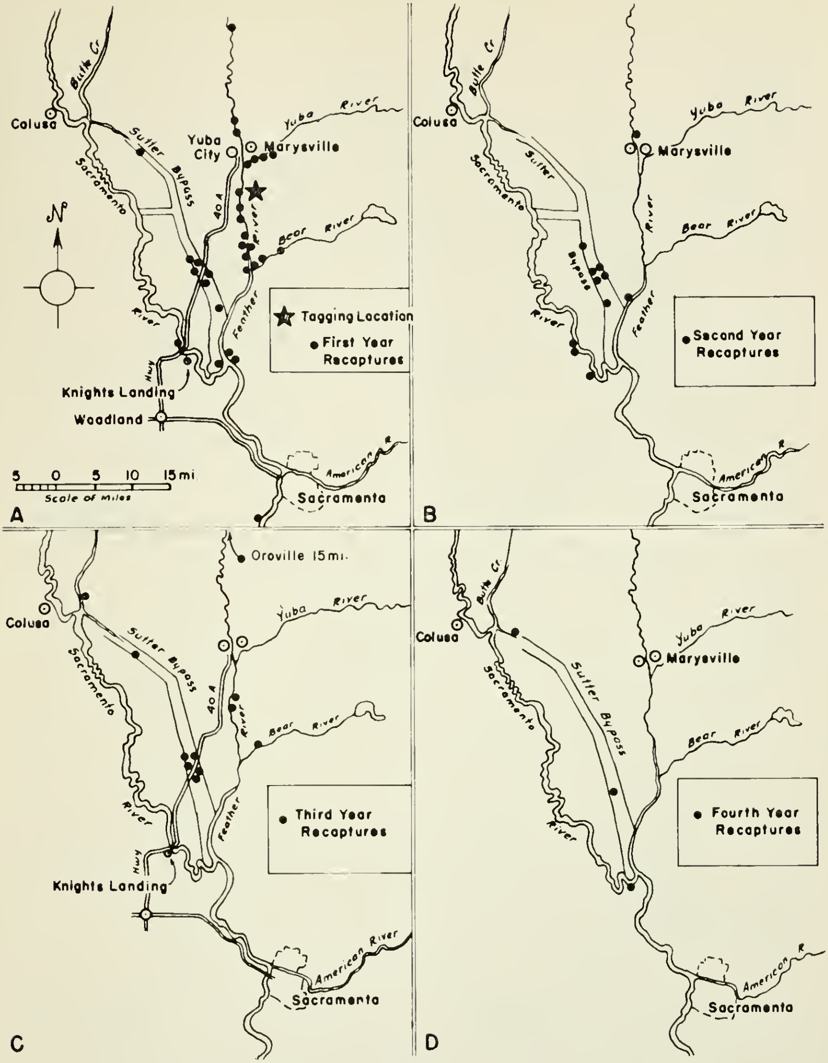

FIGURE 3. Angler recoveries of channel catfish tagged in May 1955, in the Feather River five miles below Marysville. **A,** recaptures during first year; **B,** recaptures during second year; **C,** recaptures during third year; **D,** recaptures during fourth year.

ports have been received of the limited capture of channel catfish in the lower Delta, particularly around the outfall of the Pacific Gas and Electric Company steam plant at Antioch. Oddly, all of these catches were made during the late fall or winter months, when catfish angling pressure is reduced and the metabolic rate of the fish is lowered.

The authors believe that the fish avoid the lower Delta during the summer because of a regular, seasonal increase in salinity there. Reduced river flows during the late summer and early fall allow an intrusion of brackish water from San Francisco Bay, with chlorides

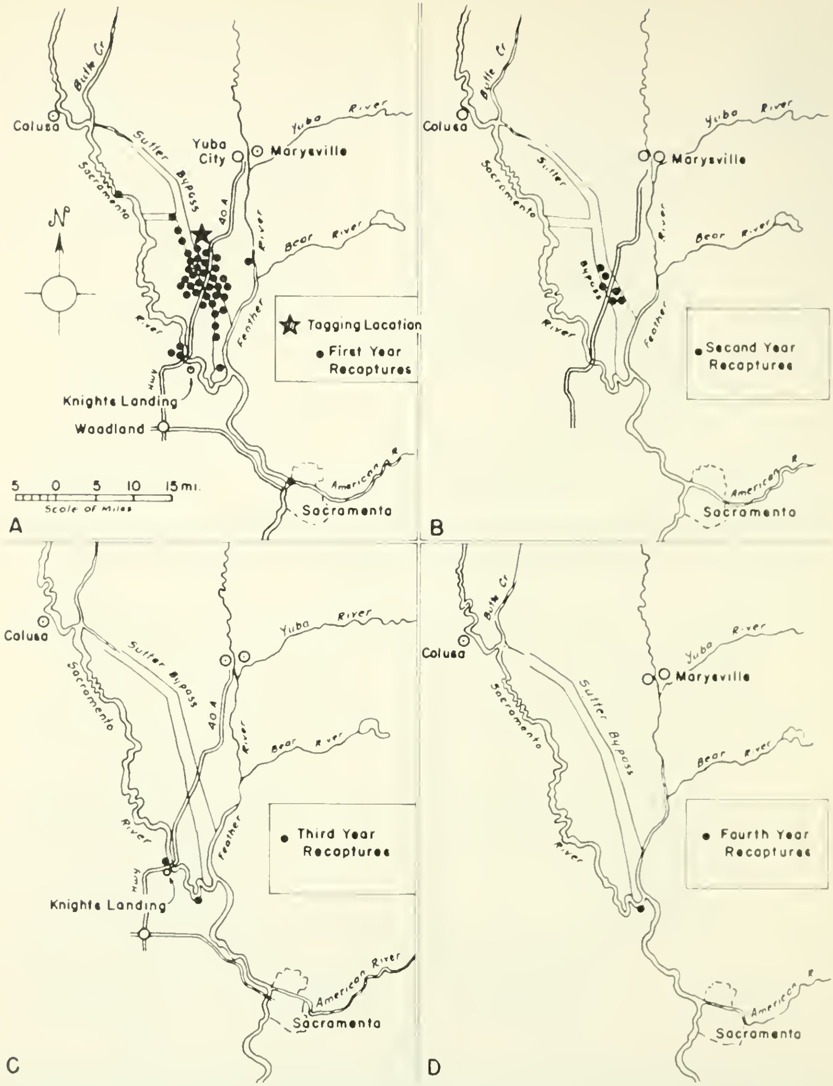

FIGURE 4. Angler recoveries of channel catfish tagged in May 1955, in the West Cut of Sutter Bypass. **A**, recaptures during first year; **B**, recaptures during second year; **C**, recaptures during third year; **D**, recaptures during fourth year.

exceeding 2,000 parts per million at Antioch Bridge during dry years. White catfish are abundant in the lower Delta. Judging by the distribution of white catfish and channel catfish in rivers of the Atlantic Coast and the Sacramento-San Joaquin River system, it is suspected that the channel catfish is much less tolerant of brackish conditions.

The movement of fish up the Feather River is obstructed by Sutter Butte Diversion Dam, six miles downstream from Oroville. However, this may be an academic point, since recaptures of fish tagged in the

Feather River indicate very little upstream movement (Figure 3). A single tag recovery was reported from the Feather River below Oroville; however, it is not known definitely whether the fish was caught above or below the diversion. A fish ladder is provided, but it is doubtful that channel catfish would negotiate it.

Another interesting facet of channel catfish movement, as revealed by tag returns, is their proclivity toward migration into Sutter Bypass from the adjoining rivers. This phenomenon is illustrated clearly in Figures 1, 2, and 3. The 63 recoveries made in the Bypass sloughs from fish released in the Sacramento and Feather rivers represents 37 percent of the total returns from the three river tagging locations.

While the rate of exploitation is considerably greater in the Bypass than in the rivers (Table 2), thus increasing the probability of capture of any fish venturing there, the fact remains that a large percentage of the population is attracted to the area. The attraction must be potent, for access is impeded on the north end. To enter the Bypass, the fish must pass through underground conduits. The forces that influence this affinity for the Bypass are not understood. Warmer water temperatures or a more abundant food supply are possible explanations.

The Bypass has a reputation among anglers for producing larger fish than do the rivers, and this concept is substantiated to some extent by the size distribution of the fish tagged there. As mentioned previously, the fish tagged in the Bypass were significantly larger than those tagged in the river. The lengths of fish tagged at the three river stations that moved into the Bypass during the first year were compared, by means of a t-test, with the length distribution of first-year recaptures from outside the Bypass (Appendix, Table A-5). The difference was significant at the 5 percent level. An explanation for the apparent greater tendency of the larger channel catfish to move into Sutter Bypass is not available.

No suggestion of a regular, seasonal migration was evident in the tag recovery data. However, it would be difficult to detect a seasonal pattern of movement unless many more fish were tagged, because angling is concentrated in the summer months. The annual distribution of angling pressure, based on tag recoveries during the four years of the study, is shown in Figure 5.

During December, 1955, only seven months after tagging was completed, a major flood occurred in the study area. The heavy flows, exemplified by the passage of 106,000 cubic feet of water per second through Sutter Bypass (California Department of Water Resources, 1957), may have profoundly affected both movement and mortality within the population. Thus, the study may have been subjected to atypical conditions. Another experiment should be carried out to either corroborate or refute the data presented here. Subsequent tagging should include an appropriate technique for obtaining an accurate measure of nonresponse by anglers who capture tagged fish.

Growth of Tagged Fish

No attempt was made to determine the growth rate of the tagged fish, since there are no means of separating accurate and inaccurate angler measurements. However, most of the anglers who returned tags

FIGURE 5. Monthly recoveries by anglers of tagged channel catfish in the lower Sacramento Valley, California, 1955-59.

during the second, third, and fourth years gave measurements that far exceeded the size of the fish when tagged. In one instance, an angler reported capture of a specimen on July 17, 1957, with a total length of 21 inches and weight of 5 pounds, 11 ounces. The angler included a snapshot of the fish, with tag still attached, that indicated his measurements were reasonably accurate. The fish was tagged on May 10, 1955, at a fork length of 13.0 inches. Thus, this fish grew about six inches in slightly over two years (total length exceeds fork length by approximately two inches in channel catfish of this size). Judging from untagged channel catfish growth rate data from other waters, this represents excellent growth.

Although the growth rate of untagged fish in this population has not been determined, there is some evidence that growth is very rapid. Mr. Gustav Geibel (personal communication) of the Central Valleys State Fish Hatchery at Elk Grove has reported that fish procured from this population for brood stock are often immature at total lengths of 20 to 21 inches. In most channel catfish populations, maturity is attained at approximately 15 inches total length. Also, limited observation of pectoral spine sections has shown that some fish reach fork lengths of 18 to 19 inches in only four growing seasons. In Oklahoma, channel catfish are usually 16.4 inches long, total length, after five years (Hall and Jenkins, 1952).

Survival and Mortality Rates

Uncorrected Data

The following calculations of survival and mortality are based wholly on concepts and methods presented by Ricker (1958). His methods are reiterated for the benefit of readers who are unfamiliar with the mathematical procedures and concepts that underlie them.

The rate of decline in the annual recaptures of tagged fish was used to obtain two estimates of the mean annual survival rate (s). These methods presume that (1) the tagged fish are subject to the same fishing and natural mortality rates as the untagged fish; (2) the tagged fish are distributed uniformly in the population; and (3) annual fishing and natural mortality rates do not change appreciably during the study period.

A weighted estimate of the annual survival rate was computed from the ratio of each year's recoveries to the preceding year's, i.e.:

$$s = \frac{R_2 + R_3 + R_4}{R_1 + R_2 + R_3} = \frac{54 + 20 + 8}{146 + 54 + 20} = 0.373$$

An unweighted estimate of survival was obtained by fitting a linear regression line to the common logarithms of annual recoveries (Figure 6). The antilog of the slope is then equal to the mean annual survival rate. The regression coefficient for the slope was —0.42151, representing a survival rate of 0.379. The close agreement between the two estimates and the close fit of the regression line indicate that survival did not vary significantly from year to year. The unweighted estimate of

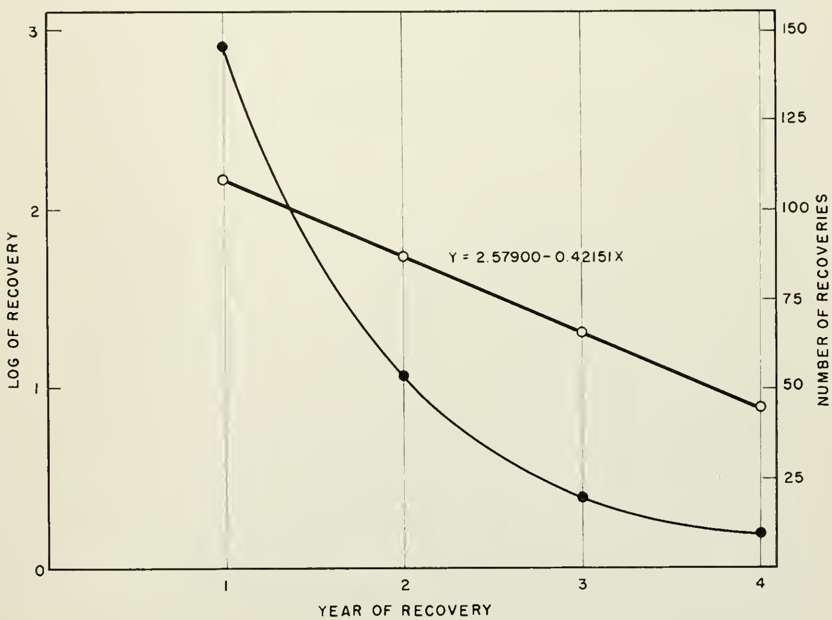

FIGURE 6. Logarithms (straight line) and actual numbers (curved line) of annual recoveries of tagged channel catfish in the lower Sacramento Valley, California.

0.379 is considered satisfactory for further computations of population parameters.

The annual total mortality rate is thus $a = 1 - 0.379 = 0.621$. This estimate is believed to be essentially free from "Type B" systematic errors (Ricker, 1958; p. 119), such as a constant rate of tag loss, a steady rate of mortality among the tagged fish that is not experienced by the untagged population, or a constant loss of tagged fish from the fishing area as a result of emigration. The estimate of total mortality is not influenced by other types of systematic error, such as an initial tagging mortality or nonreporting of tag recoveries.

When total mortality is obtained from marking experiments, it is possible to break down this parameter into its components: (1) deaths from fishing, and (2) deaths from natural causes. These mortalities can be expressed in three ways: (1) annual expectations of deaths from fishing *(u)* and natural causes *(v)*, presented as percentages of the number of fish available at the beginning of the season; (2) annual "conditional"[2] fishing mortality rates *(m)* and natural mortality rates *(n)* expressed theoretically as the percentages of the fish present at the beginning of the season that die from each cause, *on condition that* the other cause is nonoperative; and (3) instantaneous fishing rates *(p)* and natural mortality rates *(q)*, which indicate the sum of the rates at which the population decreases during successive, very brief time intervals during the season. They also indicate the fractions of the population that would die from each mortality component, if recruitment were to compensate for the mortality continuously, so that the size of the population remained constant.

The choice of which expression of mortality to employ in describing and analyzing a fishery is contingent primarily upon knowledge of the seasonal occurrence of fishing, natural mortality, and recruitment. However, exact data on the time of year that natural deaths and recruitment occur are lacking for this population. In view of this, all three numerical representations of mortality are given.

The most elementary and, under certain conditions, the most practical expressions of mortality are the annual expectations of death. These are not rates, but are simply ratios of fish deaths during a year to fish present at the start of the year. When fishing occurs at a different time of year than recruitment, these expressions are highly descriptive, in addition to being easily comprehended. However, when recruitment and fishing are concurrent, these expressions are not particularly meaningful, for in such fisheries total annual deaths can actually exceed the population present at the beginning of the year or at any other time during the year.

In this study the uncorrected mean annual expectation of death from fishing is:

$$u = \frac{R_1 + R_2 + R_3 + R_4}{M(1 + s + s^2 + s^3)} = \frac{146 + 54 + 20 + 8}{797(1 + 0.38 + 0.14 + 0.05)} = 0.182$$

[2] The term "conditional" was suggested by Dr. W. E. Ricker as a means of designating these rates more precisely in order to mitigate their confusion with the other mortality expressions.

where R equals annual tag recoveries and M equals the total number of fish tagged. The uncorrected mean annual expectation of death from natural causes is $q = 0.621 - 0.182 = 0.439$.

The concept of instantaneous mortality rates (also called logarithmic or exponential rates) has not been applied to any appreciable extent in the description and management of freshwater sport fisheries. In contrast, the use of these rates in the description and regulation of some commercial sea fisheries has been unavoidable. A lack of understanding of instantaneous rates among freshwater biologists and the fact that investigations into the dynamics of sport fish population have lagged behind studies of important marine fisheries are the principal reasons for this situation. The value of instantaneous rates will probably gain wider recognition when the need for more intensive and biologically sound management of important freshwater sport fisheries become critical.

Instantaneous rates possess certain advantages over other mortality expressions. First, they are true rates, comparable to continuous compound depreciation rates. Second, they are additive. This characteristic makes it possible to separate or combine them with simple computations. For example, if the total instantaneous mortality rate *(i)* and the instantaneous fishing mortality rate are known for a population, then the instantaneous natural mortality rate can be easily determined by $q = i - p$. Furthermore, instantaneous rates are more meaningful than other mortality expressions when the fishery under investigation is one in which recruitment, natural mortality, and fishing all occur simultaneously and recruitment compensates for mortality, so that the population of vulnerable fish remains steady. It would appear that most warmwater sport fisheries approximate this condition more closely than they do a population in which recruitment occurs at a different time of year than fishing.

The total annual instantaneous mortality rate is equal to the negative natural logarithm of the annual survival rate. In this channel catfish population, s is 0.379; thus:

$$i = -\log_e (0.379) = 0.970$$

This parameter represents the rate at which this population is decreasing continuously throughout the year, the actual number of deaths during each instant being proportional to the number of vulnerable catfish present during that same instant. For example, if the year is divided into very brief time intervals of equal duration, i.e., one-thousandths, then 0.00097 percent of the vulnerable catfish die during that interval. To further illustrate, if the initial stock consisted of 1,000,000 catfish, the number of fish that would die during the first thousandth would be $1{,}000{,}000 \times 0.00097 = 970$, and the number of survivors would be $1{,}000{,}000 - 970 = 999{,}030$. During the next interval, $999{,}030 \times 0.00097 = 969$ catfish would die and 998,061 survive. The application of this rate to 1,000,000 fish 1,000 times would result in slightly more than 621,000 deaths and slightly less than 379,000 survivors, corresponding to our previously determined total mortality of 0.621 and survival of 0.379. If the year were divided into an indefinitely large number of time intervals, so that the rate of decrease was continuous, the total deaths would be exactly 621,000. This value is not

appreciably different from the value obtained by dividing the year into one-thousandths. Even a daily instantaneous rate, given by the relationship $\frac{i}{365}$, would give results that approximate the true values with reasonable accuracy.

The above concept requires no assumptions regarding the seasonal occurrence of mortality and recruitment. However, if it is assumed that recruitment balances mortality from day to day, so that the vulnerable stock of catfish remains constant, then i also represents the fraction of the steady population that dies during the year. In this case, if the steady stock is composed of 1,000,000 fish, then 970,000 die annually from all causes. In other words, a certain number of recruits to the vulnerable stock die during the year, in addition to 62.1 percent of the initial vulnerable stock.

The instantaneous fishing and natural mortality rates are determined by the relationship:

$$\frac{i}{a} = \frac{p}{u} = \frac{q}{v}$$

The uncorrected instantaneous fishing mortality rate is 0.284 and the corresponding instantaneous natural mortality rate is 0.686.

Annual conditional fishing and natural mortality rates are hypothetical expressions when applied to most warmwater sport fisheries, since they represent the fractions of the stock present at the beginning of the season that would be killed by either fishing or natural causes, providing the other cause of death is absent. The only situation in which these expressions are realistic is when fishing occurs at a different time from recruitment and natural mortality. In such populations, the annual fishing mortality rate would be exactly equal to the total mortality rate for the fishing season and would be a real quantity. It would appear that few warmwater populations meet this requirement. Most warmwater fish populations are exploited during the late spring, summer, and early autumn, when the rates of recruitment and natural mortality usually are highest. The channel catfish population of the Sacramento Valley is no exception.

The annual conditional fishing mortality rate is given by the expression:

$$m = e^{-p}$$

where e is the base of natural logarithms. In this population the uncorrected estimate of m is 0.248.

The annual conditional natural mortality rate is:

$$n = 1 - e^{-q}$$

The uncorrected estimate of n is 0.497.

Note that the direct addition of m and n does not yield 0.621, the total annual mortality rate. Their relationship is expressed thusly:

$$a = m + n - mn$$

Annual conditional rates are obviously of limited value. They can, however, be easily converted into more appropriate mortality expressions.

Corrected Data

The failure of some anglers to report recaptures of tagged fish constitutes a serious error in this study. This type of error makes estimates of p, m, and u too small and, correspondingly, q, n, and v are too large. Estimates of total mortality and survival are not affected, since numbers of tagged fish released are irrelevant to survival computations.

Unfortunately, no valid correction factor for nonresponse is available for this study. However, data from other tagging experiments in California and in other states are available for consideration and possible application to these data.

H. K. Chadwick (unpublished data) used reward and nonreward disk-dangler tags on striped bass (*Roccus saxatilis*) in California in 1958 and 1959 to obtain a measure of angler nonresponse. The reward was \$5 and it was assumed it was sufficient to induce the return of 100 percent of the reward tags recovered by anglers. On this basis, 47 percent of the anglers who recovered nonreward tags in 1958 failed to return them. In 1959, nonresponse was 35 percent.

Butler (1957) developed a subcutaneous, vinyl plastic tag for trout and used it in several experiments with "catchable" rainbow trout (*Salmo gairdnerii*) in California. In one unpublished study, \$5 reward tags demonstrated that 38 percent of the nonreward tags actually recovered by anglers were not reported. In another experiment, \$5 reward tags were compared with subcutaneous tags for which no cash reward was offered, but which were entered in prize drawings. In this case, the returns were equal. These data are not directly comparable with the study in question, since creel census personnel were present during the entire time the tagged trout were available to the public, and angler perception of the abdominal subcutaneous tag is manifestly lower than recognition of the disk-dangler tag. In several waters where the harvest rate of "catchable" trout was already known, the use of nonreward, subcutaneous tags in experiments that were dependent wholly on voluntary, mailed returns demonstrated that the magnitude of nonresponse was between 40 and 60 percent.

Mullan (1959) estimated 60 percent nonresponse from "catchable" trout that were marked with circular monel tags on the mandible in a Massachusetts stream with a partial creel census. In another Massachusetts study, Stroud and Bitzer (1955) estimated a nonresponse of 25 percent from strap and cheek tags on warmwater game fishes when neither a creel census nor reward system was in operation. McCammon (1956) estimated only 15 percent nonresponse from channel catfish tagged with disk-dangler tags in the lower Colorado River. This estimate is now believed to be based on an erroneous assumption and is therefore lower than the true level of nonresponse.

It is evident that the efficiency of voluntary tag reporting by sport fishermen is dependent on many factors. The species of fish, type of tag, amount and kind of publicity, and degree of local interest in the outcome of a tagging experiment all influence the level of nonresponse.

On the basis of the above estimates of nonresponse, particularly the striped bass data, it is guessed that 30 to 50 percent of the anglers who caught channel catfish during each recovery period did not return the tags. The rate of nonresponse is assumed to be the same in each recovery period.

A schedule of possible mortality rates corrected for 30, 40, and 50 percent nonresponse is presented in Table 3. A best guess concerning the true rate of nonresponse might be 40 percent. At this level, u = 0.298, v = 0.323, p = 0.466, and q = 0.504.

TABLE 3

Uncorrected Estimates of Mortality in the Channel Catfish Population of the Sacramento Valley, 1955-59, with Corrected Estimates for Possible Levels of Angler Nonresponse

Mortality expressions	Uncorrected estimates	Annual percentage of nonresponse		
		0.30	0.40	0.50
Mean annual survival	0.379	0.379	0.379	0.379
Mean annual total mortality	0.621	0.621	0.621	0.621
Instantaneous mortality rate	0.970	0.970	0.970	0.970
Instantaneous fishing mortality rate	0.281	0.405	0.466	0.567
Instantaneous natural mortality rate	0.686	0.565	0.504	0.403
Annual fishing mortality rate	0.248	0.325	0.372	0.433
Annual natural mortality rate	0.497	0.431	0.395	0.331
Annual expectation of deaths:				
From fishing	0.182	0.259	0.298	0.363
From natural causes	0.439	0.362	0.323	0.258

The foregoing estimates are based on the assumption that the entire lot of tagged fish was equally vulnerable. This is not the case. As mentioned earlier, the tagged fish that were less than 9.0 inches long, fork length, were incompletely recruited during the first recovery period; hence, their rate of fishing is somewhat less than the definitive rate. The 78 fish that were under 9.0 inches fork length when tagged were therefore excluded from all survival and mortality computations. Normally, the correct procedure would be to eliminate these incompletely recruited fish at the very beginning of the computations, prior to the consideration of other errors. However, in this case the authors believed that it would be more effective to present all corrections for variations in vulnerability in the same section.

The exclusion of the partially vulnerable fish increased a by only 1 percent. The error caused by fishing during years of recruitment is apparently serious only when a large percentage of the tagged population is not yet fully recruited, or when recruitment extends over a period of several years.

A more serious difference in vulnerability is caused by the high angling intensity in Sutter Bypass. For instance, the estimate of u, corrected for 40 percent nonresponse, for fish tagged in the Bypass is 0.388, while the combined estimate for completely recruited fish tagged in the Sacramento and Feather rivers is only 0.304. It is probable that the great variation in rate of fishing makes our overall estimate of the fishing mortality rate greater than the definitive rate, since the original

calculations gave equal weight to the returns from each of the tagging localities. If one-fourth of the stock were present in the Bypass when the fish were tagged, then the Bypass returns could logically be weighted equally with the other tagging locations. However, it is extremely doubtful that the number of vulnerable fish present in the Bypass at any given time approaches one-quarter of the total stock.

Since the proportion of the stock that was present in the Bypass at the time of tagging is unknown, it is not possible to adjust the calculations so that the Bypass returns are weighed correctly. Therefore, the fish tagged in the Bypass were eliminated from consideration, and appropriate parameters were recalculated from recovery data that were obtained from completely recruited fish tagged in the rivers only. These data include the fish that were subsequently caught in the Bypass.

The final estimates of population parameters adjusted for 40 percent nonresponse and differences in vulnerability are:

Mean annual survival	= 0.440
Mean annual total mortality	= 0.560
Annual expectations of deaths from fishing	= 0.304
Annual expectations of deaths from natural causes	= 0.256
Instantaneous mortality rate	= 0.821
Instantaneous fishing mortality rate	= 0.445
Instantaneous natural mortality rate	= 0.376
Annual conditional fishing mortality rate	= 0.359
Annual conditional natural mortality rate	= 0.314

Since the growth rate of the channel catfish is unknown, the rate of fishing that will produce the maximum sustained yield per unit weight of recruits cannot be determined. However, judging from the yield curve for Type B growth of Tester (1953), it appears that the present value of p is providing a sustained yield in weight that is close to maximum.

SUMMARY

1. A substantial sport fishery for channel catfish developed about 1954 in the rivers and sloughs of the lower Sacramento Valley of California. A tagging experiment was begun in April, 1955, to obtain data on movement of the fish and mortality rates operating on the usable portion of the stock.

2. Disk-dangler tags were attached to 797 channel catfish during April and May, 1955. The fish were released in approximately equal numbers at four locations. They ranged from 6.8 to 22.1 inches in fork length, with a mean length of 12.1 inches.

3. Anglers voluntarily returned 228 tags during the following four years. Annual recoveries were: first year, 146; second year, 54; third year, 20; and fourth year, 8.

4. The locations of angler recaptures indicated that the population is essentially restricted to a relatively small area, circumscribed by Colusa on the Sacramento River, Marysville on the Feather River, and the confluence of the Sacramento and Feather rivers. Movements within this area were extensive; however, only 13 percent of the

total recoveries were recorded from outside the area. The tagged catfish demonstrated a definite propensity for migration into Sutter Bypass, a flood control channel with permanent sloughs that traverses the fishery area.

5. Estimates of survival and mortality were based on concepts and procedures presented by Ricker (1958). These estimates, corrected for an assumed rate of nonreporting of tag recoveries by anglers of 40 percent and for variations in vulnerability were:

s = mean annual survival	= 0.440
a = mean annual total mortality	= 0.560
i = instantaneous mortality rate	= 0.821
p = instantaneous fishing mortality rate	= 0.445
q = instantaneous natural mortality rate	= 0.376
u = annual expectation of deaths from fishing	= 0.304
v = annual expectation of deaths from natural causes	= 0.256
m = annual conditional fishing rate	= 0.359
n = annual conditional natural mortality rate	= 0.314

The current rate of fishing appears to be providing a sustained yield in weight that is near maximum.

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Appendix

LENGTH FREQUENCIES OF CHANNEL CATFISH TAGGED AND RECAPTURED BY ANGLERS

TABLE A-1

Number of Channel Catfish Tagged in 1955 in the Sacramento River at Sacramento Slough and the Number of Annual Recoveries, Arranged by One-inch Fork Length Intervals

Fork length in inches	Number tagged	Annual recoveries				
		First year	Second year	Third year	Fourth year	Totals
6.0– 6.9	1			--	--	--
7.0– 7.9	7	--	--		--	--
8.0– 8.9	19	2	3	--	--	5
9.0– 9.9	41	5	2	--	1	8
10.0–10.9	35	7	1	3	--	11
11.0–11.9	36	10	2	1	1	14
12.0–12.9	24	4	1	--	--	5
13.0–13.9	16	4	3	--	--	7
14.0–14.9	7	--	1	--	--	1
15.0–15.9	8	1	--	--	--	1
16.0–16.9	2	--	--	--	--	--
17.0–17.9	1	--	1	--	--	1
18.0–18.9	1	--	--	--	--	--
19.0–19.9	1	--	--	--	--	--
Totals	199	33	14	4	2	53

TABLE A-2

Number of Channel Catfish Tagged in 1955 in the Sacramento River at Butte Creek and the Number of Annual Recoveries, Arranged by One-inch Fork Length Intervals

Fork length in inches	Number tagged	Annual recoveries				
		First year	Second year	Third year	Fourth year	Totals
6.0– 6.9	--	--	--	--	--	--
7.0– 7.9	4	--	--	--	--	--
8.0– 8.9	31	2	--	1		3
9.0– 9.9	62	8	9	--	1	18
10.0–10.9	28	6	3		--	9
11.0–11.9	29	8	2	1	--	11
12.0–12.9	11	1	2	--		3
13.0–13.9	12	1	2	--	1	4
14.0–14.9	8	3	1	--	--	4
15.0–15.9	9	3		--		3
16.0–16.9	4	1	1	--	--	2
17.0–17.9	1	--	--	--	--	--
18.0–18.9	1	1	--	--		1
19.0–19.9	--	--	--	--	--	--
Totals	200	34	20	2	2	58

TABLE A-3

Number of Channel Catfish Tagged in 1955 in the Feather River, Five Miles Below Marysville and the Number of Annual Recoveries, Arranged by One-inch Fork Length Intervals

Fork length in inches	Number tagged	Annual recoveries				
		First year	Second year	Third year	Fourth year	Totals
6.0– 6.9	--	--	--	--	--	--
7.0– 7.9	1	--	--	--	--	--
8.0– 8.9	15	1	--	--	--	1
9.0– 9.9	38	5	1	2	1	9
10.0–10.9	33	7	1	1	1	10
11.0–11.9	33	5	2	2	--	9
12.0–12.9	21	1	4	3	--	8
13.0–13.9	23	7	--	2	--	9
14.0–14.9	17	2	4	--	2	8
15.0–15.9	7	2	--	1	--	3
16.0–16.9	5	2	--	--	--	2
17.0–17.9	4	--	--	--	--	--
18.0–18.9	--	--	--	--	--	--
19.0–19.9	--	--	--	--	--	--
20.0–20.9	1	--	1	--	--	1
Totals	198[1]	32[2]	13	11[3]	4	60[4]

[1] Two tagged fish were not measured; thus, the actual total is 200.
[2] One unmeasured fish was recovered; thus, the actual total is 33.
[3] One unmeasured fish was recovered; thus, the actual total is 12.
[4] Actual total is 62.

TABLE A-4

Number of Channel Catfish Tagged in 1955 in Sutter Bypass at Highway 40A and Number of Annual Recoveries, Arranged by One-inch Fork Length Intervals

Fork length in inches	Number tagged	Annual recoveries				
		First year	Second year	Third year	Fourth year	Totals
6.0– 6.9	--	--	--	--	--	--
7.0– 7.9	--	--	--	--	--	--
8.0– 8.9	--	--	--	--	--	--
9.0– 9.9	4	1	--	--	--	1
10.0–10.9	14	3	1	1	--	5
11.0–11.9	13	--	1	--	--	1
12.0–12.9	22	3	--	--	--	3
13.0–13.9	14	4	--	--	--	4
14.0–14.9	26	4	--	--	--	4
15.0–15.9	30	11	2	1	--	14
16.0–16.9	29	6	1	--	--	7
17.0–17.9	22	8	2	--	--	10
18.0–18.9	12	4	--	--	--	4
19.0–19.9	3	--	--	--	--	--
20.0–20.9	3	1	--	--	--	1
21.0–21.9	4	1	--	--	--	1
22.0–22.9	1	--	--	--	--	--
Totals	197*	46	7	2	--	55

* One tagged fish was not measured; thus, the actual total is 198.

TABLE A-5

Separate Length Frequencies of Channel Catfish Tagged in 1955 in the Sacramento and Feather Rivers, and Recaptured in Sutter Bypass and in the Rivers Proper During the First Year

Fork length in inches	Number tagged at three river stations	Number of first year recoveries		
		Outside Sutter Bypass	In Sutter Bypass	Totals
6.0- 6.9	1	--	--	--
7.0- 7.9	12	--	--	--
8.0- 8.9	55	1	1	5
9.0- 9.9	141	14	4	18
10.0-10.9	96	17	3	20
11.0-11.9	98	15	8	23
12.0-12.9	56	1	2	6
13.0-13.9	51	7	5	12
14.0-14.9	32	2	3	5
15.0-15.9	21	3	3	6
16.0-16.9	11	3	--	3
17.0-17.9	6	--	--	--
18.0-18.9	2	1	--	1
19.0-19.9	1	--	--	--
20.0-20.9	1	--	--	--
Totals	587	70	29	99

OBSERVATIONS ON THE NATURAL SPAWNING OF EASTERN BROOK TROUT[1]

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INTRODUCTION

In late September and early October, 1959, I witnessed all phases of the natural spawning of eastern brook trout, *Salvelinus fontinalis* (Mitchill), from an underwater observation tank at the University of California's Sagehen Creek Wildlife and Fisheries Station. This station is located at an elevation of 6,400 feet in the Sierra Nevada mountains, 27 miles north of Lake Tahoe in the Truckee River drainage.

As pointed out by Fabricius (1950), it is important that the releasing mechanisms of spawning and their sign stimuli be fully understood, for these determine the potential scope of environmental variations within which a species of fish is able to spawn. Knowledge of the spawning requirements of any given species will provide a sound basis for stocking in suitable waters where the greatest possible benefit can be derived through natural propagation.

Previous descriptions of the spawning of salmonids are included in the following papers: Belding (1934) on Atlantic salmon; Briggs (1953) on silver and king salmon and steelhead trout; Cramer (1940) on cutthroat trout; Fabricius and Gustafson (1954) on the Arctic char; Greeley (1932) on brook, brown, and rainbow trout; Hazzard (1932) on eastern brook trout; Hobbs (1937) on quinnat salmon, brown and rainbow trout; Jones and Ball (1954) on brown trout and Atlantic salmon; Jones and King (1949 and 1950) on Atlantic salmon; Needham and Taft (1934) on steelhead trout; Needham and Vaughn (1952) on the Dolly Varden char; Schultz et al (1935) on kokanee salmon; Smith (1941) on cutthroat and eastern brook trout; and Stuart (1953) on the brown trout. The observations of Fabricius and Gustafson (1954) and Jones and Ball (1954) were made using observation tanks or aquaria with recirculating water supplies. Jones and King (1949 and 1950) used an underwater observation tank built on the side of the River Alwen, a tributary of the Welsh Dee. Needham and Jones (1959) used the same underwater observation tank from which the observations described in this paper were made. Except for the five papers just cited, the majority of the observations reported were made from above the water where it is most difficult to properly conduct observations or to interpret them accurately.

Figure 1 indicates the physical arrangements in the pool where the observation tank is located. Two water level control dams fitted with flashboards made it possible to control depths over a range of about

[1] Submitted for publication May, 1960.

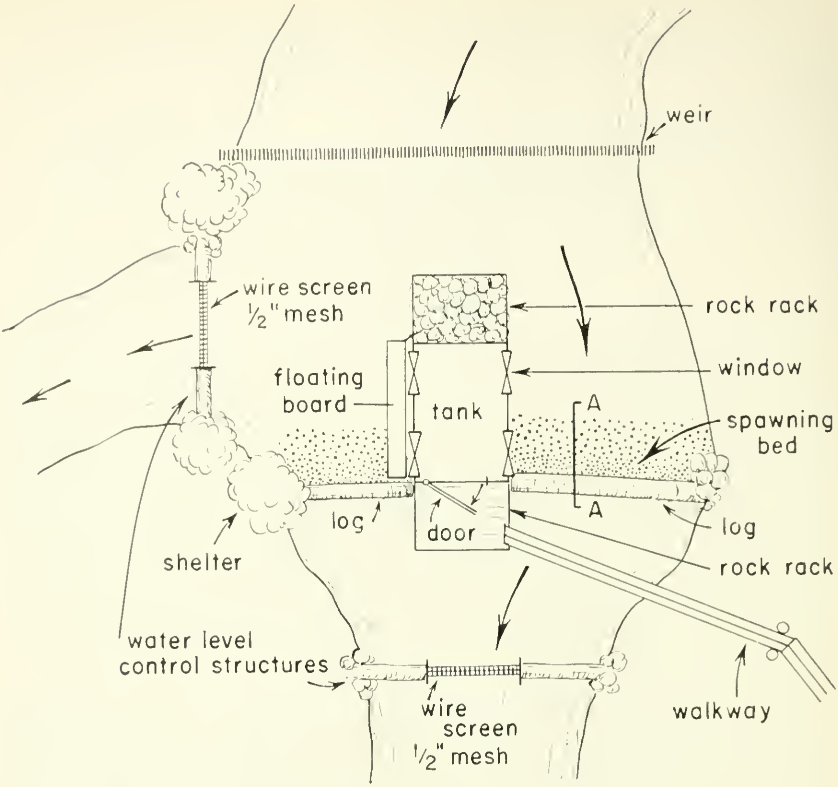

FIGURE 1. Physical arrangements at the underwater observation tank in Sagehen Creek, September 4 to October 23, 1959.

one foot. One-half-inch mesh screens fitted over these prevented escape of the fish downstream. A weir was placed about four feet upstream from the tank across the tank pool to confine the fish to the tank area. The tank and its uses were described by Needham (1956), and Needham and Jones (1959).

CONSTRUCTION OF SPAWNING BEDS

Two spawning beds were installed beside the two downstream windows on each side. These were constructed as follows: two logs were cut of suitable diameter and length to run horizontally from the posterior edge of each downstream window into the stream-bank on each side. A canvas apron about four feet wide was nailed on each log for its full length. The logs were then placed in the stream on each side of the tank so that the canvas could be laid flat on the stream bottom on the upstream sides of the logs. Each log was placed so that the line of nails where the canvas was fastened came in the middle of their upstream sides. The logs were securely fastened to the streambed by nailing to stakes driven in the bottom on their downstream sides, by wedges driven against the rock racks, and by heavy rocks placed on

the stream-side ends of each. Clean, water-washed gravel was then dumped on top of the canvas, and carefully spread to the top of each log and diagonally across each window. The canvas apron lying on the bottom of the upstream side of each log forced the water to upwell through the gravel and over the log. Most of the gravel for the spawning beds was stream-worn and well rounded, and averaged from one-quarter of an inch to about one inch in size. Figure 2 illustrates a cross section of one of the spawning beds.

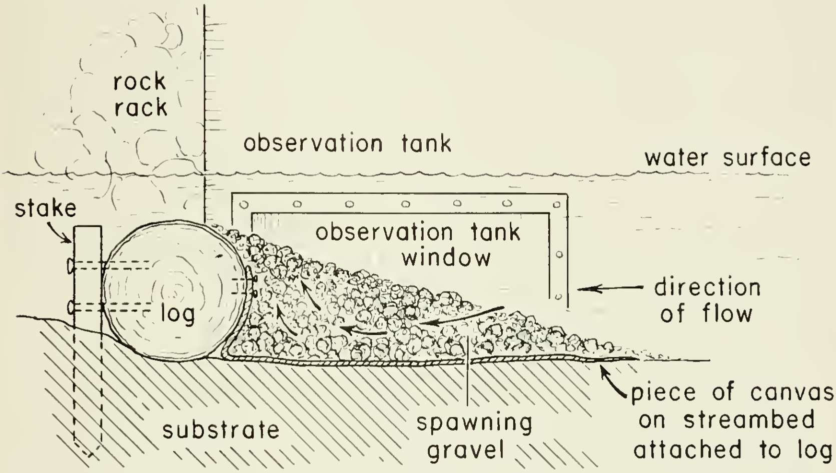

FIGURE 2. Cross section of artificial spawning bed next to observation tank window, Section A-A in Fig. 1.

Six inches of water was maintained over the logs supporting the beds on each side of the tank. As Figure 2 indicates, the depth increased gradually upstream so that at the upstream ends of the beds the depth was about one foot. The deepest part of the tank pool was approximately 22 inches, but this area was out of range of vision from the tank windows and was located just in front of the upstream rock rack. Fish, when frightened, frequently disappeared upstream in the direction of deeper water where they could not be seen. Lack of a wide area of vision is one of the real limitations in the use of a small observation tank. It would be of great value to observe the activities and behavior of fishes over much broader underwater areas.

That the spawning beds were suitably constructed was evidenced by the fact that the brook trout soon moved over them and began their normal breeding behavior. The observations reported here are largely based upon the behavior of a single pair, the male of which was around 12 inches in total length. He bore a jaw tag on the right side of his dentary bone, which had been placed there in 1954, and thus was easily distinguished from other males during breeding. His breeding color consisted of brilliant red on the belly, fiery red lower fins with the usual white bands followed by black on their anterior margins, and strong teeth developed on an upturned lower jaw. The female was about nine inches in length, and her breeding coloration was much duller than that of the tagged male.

Five other males and three other females had been placed in the tank pool. Two of the excess males were also fairly large fish, ranging about 10 inches in length, while the other three were from 5 to 7 inches in length. Three sexually mature brown trout *(Salmo trutta)* had also been placed in the tank area, of which one was a female about 10 inches, and two were males approximately 14 inches and 16 inches in length. The brown trout in the pool were never observed to spawn in the daytime. Evidently, they sensed the artificial nature of the arrangements around the tank and were suspicious of it. However, at night they were observed on the extreme edge of the south spawning bed; and much disturbance of the gravel was observed after daylight, which gave evidence that they were spawning only at night. A flashlight suddenly turned on them at night would drive both species into shelter underneath the roots of a tree on the bank side of the redd or into deeper water out of range of observation behind the weir above the tank.

Five rainbow trout (*Salmo gairdnerii*) between five and nine inches in length were also placed in the area, in order to observe their behavior with respect to the spawning activities of the eastern brook trout.

Practically all the spawning activities reported here were observed through the rear south-window of the tank and took place underneath a board that had been floated on the surface to provide shelter. The spawning area on the north side of the tank had not been provided with such floating shelter and was little used, although nest building operations were observed there occasionally. Another factor that frightened the fish on this spawning area was movement of the persons going in and out of the tank via the walkway that passes some three feet over one corner of the area. Means of screening movements of personnel, such as the tar-paper blinds used by Needham and Taft (1934) and Smith (1941), make it possible to conduct observations without disturbing the fish.

A strobe light used in taking pictures did not unduly disturb the fish except that, early in breeding activities, the big male that mated with the female described above would sometimes jerk back three or four inches from his place beside the female immediately after the flash. Later at peak of spawning, however, no reaction was noted by this or other fish to the flash of the strobe.

PRE-SPAWNING ACTIVITIES

On September 25, the tank pool was stocked with the trout noted above. They were taken using a direct current shocker from closely adjacent stream sections. Within two hours they had evidently completely recovered from the shocking and handling, and two of the larger males began courtship behavior. In its early stage, this consisted of attempting to drive or to guide a female from the deeper water near the upper windows of the tank downstream to the spawning beds in shallower water beside the downstream windows. To do this, he usually swam close beside the female and slightly ahead of her on her upstream side, gently turning her toward the redds. Frequently the female refused the escort and turned back to deeper water. Evidently, the females were still in the process of maturing; for a week later such

actions to herd the females toward the redds were unnecessary, and they remained constantly over the redds except when frightened.

One characteristic feature of pre-spawning activities of the female was searching or looking over the bottom for a suitable spawning area. She arched her back and held her head close to the bottom as her eyes were seen to turn downward in close inspection of the gravel. While doing this, she was constantly courted by the male. A similar type of searching is described for the female Arctic char by Fabricius and Gustafson (1954) and by Jones and Ball (1954) for the brown trout and Atlantic salmon. The tagged male spent most of his time driving off other males, not sharing at all in the cutting of the redd with the female. In addition, he frequently courted the female by suddenly darting alongside of her and quivering slightly. He also swam over and under her, frequently rubbing his fins against her as he did so. The movement of both fish is practically constant—the female being occupied with cutting the redd, and the male with courtship actions and aggressively driving other males away. The female shared in the repulsion of other males that constantly gathered near the nest area evincing much interest and evidently intent upon sharing in the spawning act.

The female in cutting, turns on her side and by means of rapid, vertical movements of her tail fin, sucks gravel, silt and debris from the bottom. The smaller stones and silt are swept away by the current but the larger quickly settle to the bottom, forming a mound just below the bed. Actually, this operation appears somewhat like a swimming motion made while turned on her side. The head also moves up and down in the same direction as the tail, but its movement is less pronounced than that of the tail. The force of the cutting motion may cause the female to move a foot or so beyond the area being cut, but repeated digging movements soon produced a depression four to six inches in depth for the reception of the eggs. Jones (1959), who took slow motion films of the cutting action of the Atlantic salmon, *S. salar*, states that with this species, ". . . it is apparent that the female starts a cut from her normal position, that is with head upstream, body on an even keel and almost parallel to the river. She then turns over on her side, usually by first rotating her caudal fin so that it rests almost flat on or near the gravel and then by a lesser rotation of the body, which in this phase is tilted at about 45 degrees. Then the posterior half of her body is bent sharply downwards and her caudal fin rests fanned out on or near the gravel. . . . From this position follow rapid straightening (the upstroke) and bending (the downstroke), so that the posterior region of her body is thrust vigorously upwards and downwards from and to the gravel. This action of flexing and straightening the body is repeated several times in rapid succession. In the more vigorous cutting movements the anterior part of the body may be more bent, so that the fish is an inverted U. Throughout these movements, the pectoral, pelvic and dorsal fins are erected, and the mouth is slightly opened. I believe that the vigorous downstroke of the posterior half of the body thrusts the water against the gravel with sufficient force to loosen it. Certainly the upward flexion sucks gravel upwards: individual stones can be seen to follow the tail-fin until they are caught in the current and carried downstream. The complete action of flexing and straightening

of the body constitutes one cutting movement, and a complete series of such movements, beginning and ending with the fish in its normal position on an even keel, is called a cut. A weak cut consists of only a few slow and languid cutting movements; a strong cut may consist of as many as a dozen vigorous cutting movements in rapid succession, at the rate of about three or four a second. The female tests or feels the effect of her cutting by means of her anal, caudal and pelvic fins. . . ." The cutting action of the brook trout appeared similar in all respects to that of the Atlantic salmon.

The trembling or quivering movements observed in courtship have been shown by Fabricius and Gustafson (1954), to actually be very swift undulations. This was determined from slow-motion pictures. They say (p. 74) that, ". . . waves of lateral contortions travel rapidly from the cranial to the caudal end of the body." During nest-cutting operations the tagged male accompanying the female became highly annoyed at a five-inch male eastern brook trout that was persistently trying to get into the nest area. The annoyance apparently came to a head when he seized this small fish across the back between his jaws, released him for a moment, and then seized him again in the same fashion and shook him much like a dog shakes a rat. It appeared first that he was going to eat him, but this did not occur. Close observation of the small fish next to the window did not reveal any teeth marks or any injury. The attack did not daunt him in the least, for he continued to harass the large male.

As noted by Needham and Taft (1934), Smith (1941), and other workers, breeding activities continued both day and night. Changes in the shape and size of the redds were noted from day to day—changes which could only have been made at night when observations could not be made.

THE SPAWNING ACT

This spawning act was first seen on October 10, 1959, at 12.40 p.m. The female was observed to drop her anal fin deeply into the pit, arching her tail at the same time. The male promptly took his place beside her. Both opened their mouths wide and appeared to tremble while milt and eggs were emitted simultaneously, the entire act lasting no longer than about one second. None of the other males present were seen to dart into the nests on the opposite side of the female and share in the spawning act. Smith (1941) reports observing two males sharing in the spawning act in one out of three spawning acts observed by him.

Because the male took his position on the right side of the female between the window and the female, and because of the white cloud of milt extruded, it was impossible to observe the eggs falling into the bottom of the nest. However, the pale yellow eggs could be seen clearly in the bottom of the pit after water currents had washed away excess milt. The milt was observed to hang in the current eddies in the pit, spreading laterally and even upstream a bit before finally disappearing. The bottom of the pit was some four inches below the edges of the nest. This provided a pocket of quiet water, where the eggs were dropped and where fertilization must have occurred almost instantaneously. Hobbs (1937), Cramer (1940), and Smith (1941)—all observed the cloud of milt, but only Smith noted the spread of the milt upstream and sidewise in the nest because of current eddies.

The position taken by the female in the actual spawning act was termed "a crouch" by Jones and Ball (1954) in observations of the spawning of Atlantic salmon and brown trout. They also observed that the orgasm lasted only one or two seconds in brown trout, while that of the salmon required approximately 10 seconds. About a second was required for completion of the act in the eastern brook trout; and in this respect, they parallel brown trout.

Fabricius and Gustafson (1954, p. 99), in their description of the spawning act of the closely related Arctic char *Salvelinus alpinus,* state that when ready to spawn, "the female shows a signal movement which could be called anchoring. She suddenly stops in the center of the nest pit, lowers her anal fin down into some crevice in the bottom, bends her body backwards, trembles and opens her mouth. The male responds by swimming up parallel to her, and both fishes swim side by side across the pit in a spawning act, squirting out their sexual products." On the same page they also state that, "After 1 to 5 successive spawning acts the female performs snake-like undulating movements," to cover the eggs with gravel. In contrast with their observations, the pair of eastern brook trout observed in Sagehen Creek remained stationary over the nest pit during the spawning act, not swimming over the pit while discharging the sex products. Furthermore, the pair spawned only once, after which the female immediately covered the eggs, using the undulating movements described below.

POST-SPAWNING BEHAVIOR

Immediately after spawning the female eastern brook trout began what may be termed a "post-nuptial" dance. This is beautiful to watch and is quite a different method of covering the eggs than that used by rainbow or steelhead, cutthroat, or Atlantic salmon. While Smith (1941) described this process from a blind above the water, I am able to add more details. After dropping the eggs, the female immediately began a sinuous, weaving motion, using the ventral tips of the caudal and anal fins to roll gravel gently into the nest over the eggs that could be clearly seen on the bottom of the pit. The motion consisted of weaving her head and caudal fin gently back and forth in the same direction, with the head raised high over the redd and the anal and lower tip of the caudal working over the gravel adjacent to the eggs. That she knew precisely the spot where she had dropped the eggs, was evidenced by the fact that not once did she work the caudal directly over the eggs themselves. Her anal fin was curved into a somewhat shovel-like position into the gravel and pushed pebbles slowly into the egg pit. The gravel was small, mostly around one-quarter of an inch in size, and usually only a single pebble or two moved with each individual sweep. She had the eggs completely covered in four minutes. She circled the pit in this manner with the head directed outward and her caudal portions inward, near but not over the eggs, for around half an hour. After 30 minutes, and after she must have known the eggs were deeply covered, she would occasionally begin the characteristic digging or cutting movements upstream some eight inches above the pit where she last deposited the eggs. By 1.45 p.m., she was regularly cutting a new nest and had ceased egg-covering movements.

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While covering the eggs, she was most aggressive in driving away immature eastern brook and rainbow trout. She would attack them viciously at times, opening her mouth to bite them. The male, on the other hand, seemed quite docile during this period and hung around the downstream edge of the nest doing little to aid the female in driving other fishes off the nest area. Some 10 to 15 minutes after the spawning act, the male that had mated with her departed for some other place in the pool while she continued to cover the eggs. During the process of covering the eggs, one of the large male brown trout came cruising by the redd. She ignored him, but she drove off all other fish that attempted to come near. The next morning the redd was beautifully rounded and topped with small pebbles.

None of the other fish in the pool were allowed close enough to the nest by the female at any time to secure eggs. This observation would tend to give assurance of minimal losses by predation during the spawning process. Some of the smaller males were frequently aggressive, and much of the female's time was spent fighting them off. One of the small males was observed to grab her caudal peduncle in his jaws, even though he was much smaller in size. This I judge to be part of the courting act rather than an act of aggression.

The actual spawning act by the same pair was observed again at 11.05 a.m. on October 11. This time the nest had been dug about 12 inches upstream from where she spawned on October 10. Observations were started at 10.50 a.m. It was possible to tell that she was almost ready to spawn because she was feeling deeply into the pit with her anal fin and still turning on her side, and digging once or twice a minute. The same behavior occurred after spawning as was observed the day before. The female immediately started the beautiful undulating motion to cover the eggs. The same tagged male mated with her and this time he remained only three or four minutes, after which he departed. After spawning he became far less aggressive towards other males. Again after her mate departed, the small eastern brook males, some five of them, gathered around evincing interest in her.

Once the female, in between undulations in pushing the gravel over the eggs, swam over and rubbed her fins over the male with whom she had just mated, seemingly to perform an act of courtship toward him. No other males were in on the spawning process other than the large male that attended her at all times, except immediately after spawning.

The smaller males in the pool became quite excited just before the actual spawning act and vigorously attempted to intrude into the nest area. What attracted them is not known, but possibly it was the motions of the female that indicated that spawning was about to occur. In any case, the male was kept busy driving smaller males away.

On October 11, she had deposited her eggs in much larger gravel but, even so, had no difficulty in covering them deeply. She never turned on her side and cut vigorously in the area in which the eggs were laid, although she would occasionally go through a sort of half-hearted cutting motion a foot or so upstream from the point where the eggs were deposited.

WATER TEMPERATURES DURING SPAWNING PERIOD

Air and water temperatures are continuously recorded at Sagehen Creek with a two-pen, Taylor recording thermometer. Daily maximum and minimum water temperatures between August 31 and October 25 are presented in Figure 3. Highly-colored male brook trout were observed in the tank pool as early as September 15. Peak of spawning occurred between October 1 and October 15, after minimal water temperatures had dropped to between 37 and 44 degrees F. Daily mean water temperatures ranged between 43 and 46 degrees F. during this period. It is my observation that male trout mature sexually before females, and if the date of appearance of ripe males in Sagehen Creek is taken as the start of the spawning season, then September 15 could be considered the beginning of breeding in 1959. Female brook trout stayed near the redds until around October 25, in the post-spawning period after the males had lost interest and departed. The full spawning season could be estimated to run from September 15 until October 25. In Figure 3, it will be noted that a rapid drop in temperature occurred starting on September 15. This may have served as a releasing mechanism, for spawning activities were initiated immediately afterward.

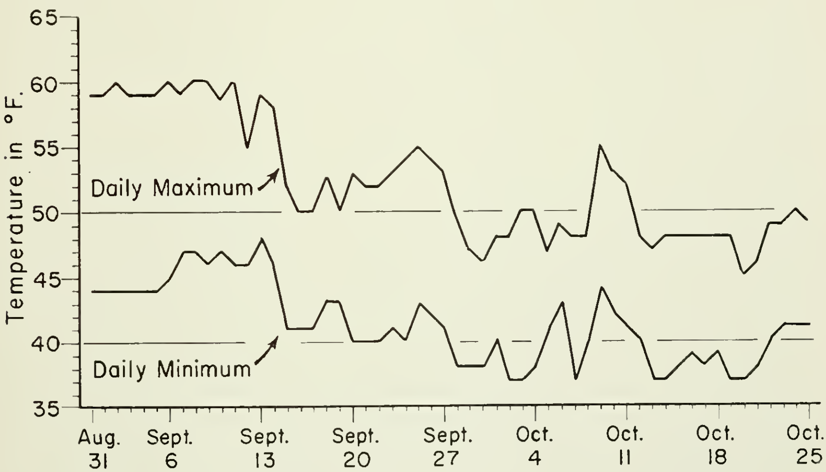

FIGURE 3. Water temperatures—Sagehen Creek August 31 to October 25, 1959.

Fabricius and Gustafson (1954) noted that the Arctic char spawned at temperatures ranging between 38.3 and 54.5 degrees F. (3.5 and 12.5 degrees C., respectively); Jones and King (1949), in work on Atlantic salmon, reported that spawning took place between 36 and 42 degrees F.

WATER VOLUME DURING SPAWNING

A gaging station is operated jointly on Sagehen Creek by the University of California and the Water Resources Division of the U. S. Geological Survey, using a Leopold-Stevens A35 gage-height recorder. It is located approximately one-quarter of a mile below the observation tank. Discharges between September 1 and October 31 were quite even

for the most part, ranging between 1.4 and 1.9 cubic feet per second (c.f.s.). An early fall storm on September 18 raised the flow suddenly to 6.1 c.f.s., but by September 21 it had dropped back to 1.9 c.f.s. Over the peak of the spawning period between October 1 and 15, discharges ran between 1.7 and 1.9 c.f.s. In other words, volume of flow was low and even, without any disturbance by severe flooding.

DISCUSSION

The main environmental factors inducing the appropriate physiological condition for spawning in an adult brook trout are day length and water temperature. Selection of the actual spawning site is determined by visual stimuli of particle sizes seen by the female, possibly coupled with water movements. Actual mating behavior, on the other hand, is related to exchange of various physical stimuli or releasers during fighting and courtship.

Clear experimental evidence is presented by Fabricius and Gustafson (1954), indicating that nest-digging movements of the Arctic char (*Salvelinus alpinus*) may be released by visual stimuli. These workers covered suitable spawning gravel areas with smooth glass plates, and the females performed normal digging movements and spawned only on that portion of the plates that were located over suitable-sized gravel. Large, flat stones laid in the bottom—even though they were not covered by the glass plates—were ignored as spawning sites, indicating that gravel size was of major importance.

Just what part water movements play in the selection of spawning sites by trout, char, or Atlantic salmon is uncertain. The experiments just cited, as well as those reported by Jones and King (1949 and 1950) and Jones and Ball (1954), were conducted in aquaria or tanks of various types with surface current speeds ranging from 1.0 to 1.5 feet per second. Some half-dozen natural nests of eastern brook trout were observed in Sagehen Creek in the open stream below the tank area in the fall of 1959, and all of these were located in fairly rapid currents and usually at the lower ends of pools where there was gravel of suitable size. That this species spawns successfully in lakes (Needham and Sumner, 1941) is well known, and the areas selected are usually those gravel beaches where upwelling seep-water occurs. The reason that most species of trout select the lower ends or "tails" of pools is because the large amount of water passing through the gravels assures the eggs a constant supply of well-aerated water during incubation. As pointed out by Fabricius and Gustafson (1954), one of the most important functions of the nest-digging movements is to increase the permeability of the bottom materials by removal of loose, fine materials that would tend to clog the spaces between the stones and thus reduce water circulation around the eggs. They say (pp. 95 and 96), "deposition of the eggs in a permeable material is secured both by a mechanism leading the female to a place where the bottom has this character, and by instinctive movements which further increase the permeability of the material at the chosen nest site. The anchoring also cooperates in securing the deposition of the eggs in a permeable material, for this act, which immeditely precedes egg-laying, can be

performed only at a place where the crevices are so deep that the anal fin of the female can sink down in them."

In the "crouch" or "anchoring" of the female eastern brook trout observed in Sagehen Creek, it was noted that once a fairly well-formed pit had been dug, she appeared to test its depth frequently with her anal fin, moving it slowly over the gravel in the bottom by arching her back but without giving the sign stimulus for the actual spawning act. Just prior to the first act, she seemed to push the middle portion of the anterior rays of her anal fin rather constantly, for several moments at a time, against one of the larger stones in the deepest part of the redd. The tip of the fin, in this instance, was out of sight in the deepest pocket. She seemed to repeatedly "test" the character of the pit as to depth, width, and other characteristics. Within a few moments after this behavior, the actual breeding act was observed.

Dr. J. W. Jones wrote as follows (March 3, 1960; personal communication) regarding the use of large stones in a bed by the female: "Trout and salmon females spend a great deal of time placing two or more larger stones in a suitable position at the bottom of the bed in between which the anal fin fits snugly when the female is crouching. I feel certain that the female positions these so that her eggs will pass into the crevice in between these large stones." While the female I observed did not attempt, apparently, to actually position larger stones in the bed, it was noted that she utilized the larger stones already present by carefully making the deepest part of the pit just in front of one or two such stones, and in front of which her anal fin fitted "snugly". This exemplifies the extreme care with which each pit is prepared by the female for the reception of the eggs.

The most complete discussion of the various stimuli involved in breeding of salmonids is found in papers by Fabricius and Gustafson (1954) and Jones and Ball (1954). Fabricius and Gustafson, in discussing the findings of Jones and Ball, point out that while there are many striking similarities between the behavior of brown trout and the Arctic char, there are also some sharp differences. For instance, the Arctic char and brown trout often bite their opponents. This is also true of the eastern brook trout and also of the Atlantic salmon. Similarly, the brown trout, Atlantic salmon, and eastern brook trout spawn but once in a single pit, and the females begin to cover the eggs immediately afterward, whereas the Arctic char will perform several spawning acts in each pit. This observation is confirmed in work by Dr. Winnifred E. Frost (1956). She observed that with the eastern brook trout only a single orgasm takes place over a single pit, whereas with the Lake Widermere char (*S. alpinus*) two to seven usually occur. Frost also reports the undulating movements used by eastern brook trout to cover the eggs, stating (p. 31), "the female moved stones as big as walnuts with her tail and covered the eggs to a depth of an inch." Both the eastern brook and the Arctic char use similar undulating movements to bury the eggs. The above papers each present different interpretations of courtship behavior, especially with respect to the trembling or quivering movement exhibited. Readers are referred especially to Tinbergen (1951) for the broader outlines of this process of animal behavior.

In small streams, it is easy to locate and to count redds. The shallow gravel areas in which the females dig are quite noticeable to the eye once one becomes familiar with their appearance. All sediment and silt is washed away, and they appear—when completed—as small, nicely rounded piles of clean gravel. Unworked areas, by way of contrast, appear undisturbed and darker in color from fine layers of sediments on the gravels.

Oftentimes one can locate spawning fish simply by the noise made by the females during digging operations. I have located redds of steelhead, cutthroat, brown and eastern brook trout by the noisy splashing actions of females during breeding.

Much more thorough information is needed on such details as water volumes and direction of flow through redds, size and position of gravels selected, and water temperatures during spawning. Of greater importance would be information dealing with population densities on spawning areas in relation to subsequent hatching and survival of young. Where fish are crowded on limited gravel areas, and where their density is such that late-spawning fish may dig up and destroy or make accessible to predators eggs laid by early spawning females, heavy losses result. By knowing in full the spawning requirements of each species and the optimal densities in relation to space and survival, it should be possible to install suitable spawning beds—or improvements to them—that would be utilized by the fish where such facilities are lacking, scarce, or crowded. Proof that trout can be induced to use artificially constructed redds is presented here and in a number of the papers cited.

ACKNOWLEDGMENTS

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SUMMARY

(1) Spawning behavior of a single pair of eastern brook trout, *Salvelinus fontinalis*, was studied in Sagehen Creek, California, from an underwater observation tank.

(2) Two artificial spawning beds were constructed of gravel beside the two downstream windows of the tank. These proved most successful—the fish moving on to them promptly after they were installed. Washed gravel of walnut size and smaller was used.

(3) The pair observed was quite territorial, driving away all invaders aggressively from their nest area. No color changes were observed in the trout while assuming threat postures.

(4) Brown trout, *Salmo trutta*, stocked in the tank pool, spawned only at night, while the brook trout appeared to spawn both day and night. Rainbow trout, *Salmo gairdnerii,* did not molest the spawners at

any time, nor were they observed to attempt to eat eggs deposited in the redd.

(5) Spawning activities of the female consisted of searching for a suitable nest site, nest cutting, testing of nest site by "anchoring" or "crouching," actually spawning, and covering eggs. During the latter process the female went through a kind of a "post-nuptial" dance in which she performed a weaving, undulating movement using the ventral portions of anal and caudal fins to gently push gravel into the pit over the eggs. After actually spawning once, she immediately began to cover the eggs.

(6) The activities of the male were largely related to aggressively fighting off all intruders into the nest area and in sharing in the spawning act. He did not share in the cutting of the nest.

(7) The female, when ready to spawn, produced an appropriate signal movement when her anal fin was in the deepest part of the pit. The male swiftly took his place beside her; both opened their mouths wide and trembled while eggs and milt were emitted simultaneously. About one second was required for each of the two acts observed.

(8) The peak of the spawning period in Sagehen Creek occurred between October 1 and October 15—when daily, minimum water temperatures ranged between 37 and 44 degrees F. Volume of water flow varied from 1.7 to 1.9 cubic feet per second over the same period.

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CORRELATION OF FOOD HABITS AND ABUNDANCE OF WATERFOWL, HUMBOLDT BAY, CALIFORNIA[1]

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INTRODUCTION

Humboldt Bay, located along the northwest coast of California in Humboldt County, is over 200 nautical miles north of San Francisco and approximately 180 nautical miles south of Coos Bay, Oregon. The width of Humboldt Bay varies from one-half to about four miles, and its length is approximately 14 miles. At high tide the water in the bay covers 24.5 square miles and at low tide 7.8 square miles. Two long narrow sand spits separate the north and south bays of Humboldt Bay from the ocean (Anonymous, 1955).

Habitat types near the bay include coastal dunes on the west side, urban and agricultural on the north, east and south sides, and redwood forest type on the coastal mountains located immediately inland from the urban and agricultural areas (Yocom and Dasmann, 1957). The agricultural lands are used primarily for dairy cattle pasture. Remnants of tide channels, now blocked off by dikes, occur in the pasture lands. These old channels fill with fresh water during the rainy season in early fall to late spring. They provide habitat for aquatic plants used by waterfowl.

RELATIVE ABUNDANCE OF WATERFOWL

An aerial inventory of the waterfowl in the Humboldt Bay area was taken by Bentley and Christianson (1957). Sixteen flights were made between October 16, 1956, and April 15, 1957. The highest concentration was noted in January 1957, when over 50,000 birds were present. From this inventory and other field studies the authors calculated the average number of waterfowl by species for each month included in the study. Monthly averages of waterfowl species were totaled which indicated the relative abundance of each species for the entire period. These numbers were converted to percentages (Table 1).

The seven most common waterfowl species utilizing Humboldt Bay were widgeon (*Mareca americana*), black brant (*Branta nigricans*), pintail (*Anas acuta*), canvasback (*Aythya valisineria*), coot (*Fulica americana*), lesser scaup (*Aythya affinis*) and greater scaup (*Aythya marila*). Lesser and greater scaup were treated as one group because of the difficulty of differentiation in the field. However, we estimated the wintering populations of greater scaup in Humboldt Bay to be larger than the lesser scaup populations.

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TABLE 1

Relative Abundance of Waterfowl from October 16, 1956-April 15, 1957, Humboldt Bay, California

Species	Percent of total	Species	Percent of total
Widgeon	47.1	Mallard	.3
Black brant	20.2	Shoveler	.3
Pintail	15.6	Whistling swan	.2
Canvasback	4.2	Scoter (3 species)	.1
Coot	2.7	Ruddy duck	.1
Scaup (greater and lesser)	2.5	Gadwall	trace
Buffle-head	.7	Canada goose	trace
Redhead	.6	Unidentified	4.8
Green-winged teal	.4		

The relative abundance figure for scoters, which includes white-winged scoter (*Melanitta deglandi*), surf scoter (*Melanitta perspicillata*) and an occasional American scoter (*Oidemia nigra*), apparently is low (Table 1). These birds were difficult to identify and count from an airplane or ground station because they occur singly and in small groups dispersed over Humboldt Bay.

FOOD HABITS STUDIED

From 1953 to 1959 the authors compiled data on the food habits of Humboldt Bay waterfowl. Howard Leach, California Department of Fish and Game biologist, examined eight of the brant gizzards. Robert Talmadge, Willow Creek, aided in the identification of mollusks. A total of 393 gizzards of 11 species have been examined (Table A-1). Each plant item represents seeds unless otherwise indicated.

The methods used in analyzing food contents in the duck stomachs were the same as those discussed by Yocom (1951).

RELATIVE IMPORTANCE OF FOOD ITEMS

In evaluating the importance of the food sources to the total waterfowl population feeding in the Humboldt Bay area, food habits have been correlated with the abundance of each species of waterfowl. The volume of each food item eaten was assumed to indicate the importance of the item to the particular waterfowl species. To evaluate the importance of a specific food item to the total waterfowl population, we considered the total number of waterfowl of all species consuming a specific item. For each species of waterfowl the values in the percent of total volume column were multiplied by a figure representing the relative abundance of that waterfowl species in the Humboldt Bay area. This procedure results in a ''volume index.'' The volume rates for a food item for all waterfowl consuming it were added resulting in a figure representing an index of the importance of each food item to the total local waterfowl population (Table A-2).

DISCUSSION

Eelgrass (*Zostera marina*) is by far the most abundant waterfowl food plant in this area and is available to all waterfowl utilizing the

open water of Humboldt Bay. Keller (1960) estimated 840 acres of eelgrass beds in the north and 2,015 acres in the south bays. Eelgrass was the principal food for widgeon (*Mareca americana*) and black brant (*Branta nigricans*) whereas the other waterfowl ate it only occasionally. Brant were, for the most part, dependent on eelgrass for food (Cottam and Monro, 1954, and Cottam, 1941), but widgeons fed on several different green plant foods in different locations.

Since widgeons in the Humboldt Bay area fed in fields and sloughs as well as on the bay, it appeared that their heavy utilization of eelgrass resulted from the availability and acceptability of the eelgrass rather than because of dependence upon it. The materials listed as "unidentified vegetation" under widgeon and brant in Table A-1 consisted principally of small fragments of eelgrass, clover, and grasses.

Analyses of foods consumed showed that pintails ate plant foods commonly found in the shallow areas of the bay and in marshlands adjacent to it. Eelgrass was found in only one sample.

Mallards *(Anas platyrhynchos)*, which represented less than 0.5 percent of the wintering and migrating waterfowl populations, apparently obtained only a small portion of their food from the bay. The relatively small resident population and others that migrated to this area fed in the outlying ponds, marshes and streams where bulrushes *(Scirpus* spp.), spike rush *(Eleocharis macrostachya)*, mare's tail *(Hippuris vulgaris)* and other species listed in Table A-1 were more abundant. When disturbed by hunters, they use the bay or the open ocean as escape areas. Eelgrass was found in only two samples. In recent years many of the coastal marshes have been eliminated by dikes, earth fill and drainage thus reducing the number of mallards that nest and winter there.

Green-winged teal *(Anas carolinensis)* also used the marsh areas along old tide channels and coastal marshes near the bay for most of their food supply.

Canvasbacks relied on animal food, pondweeds *(Potamogeton* spp.) and widgeon grass *(Ruppia maritima)*. Eelgrass was found in only one specimen. Animal food from the bay was important in the diets of lesser and greater scaups and buffleheads *(Bucephala albeola)*. Eelgrass apparently was not an important food for these three species, because it was found only in two greater scaup.

White-winged scoters ate primarily mollusks from the bay, whereas ruddy ducks *(Oxyura jamaicensis)* consumed primarily plant material of which widgeon grass was the most important.

Barley *(Hordeum vulgare)* was taken in relatively large amounts by mallards and pintails although little is grown in the area. Some barley may have been obtained from baited hunting ponds. Creeping spike rush occurred frequently in green-winged teal, pintail, mallard, and widgeon stomachs, and in small amounts in ruddy and bufflehead stomachs.

It should be noted that a food habits study indicates the food items consumed during the study, and not necessarily innate preferences of the waterfowl concerned. The food taken at any one time depends on both the preferences of the waterfowl and the availability of the food items. Thus as the availability of any food item changes, the food habits

and possibly the relative abundance of the waterfowl may change because of movement into and away from an area. For example, it seems likely that an increase in the availability of barley and other grains in this region could result in larger winter populations of pintails and mallards.

According to reports of people who lived in the Humboldt Bay area twenty or thirty years ago, geese other than black brant wintered there. At that time some fields on Table Bluff south of Humboldt Bay and elsewhere in the area were producing harvestable crops of mature oats *(Avena sativa)*, barley and wheat *(Triticum aestivum)* which undoubtedly furnished feed for the geese and grain-eating ducks. Under a grain-growing type of agriculture there would be a change in the percentage of species of waterfowl wintering in this region.

This study indicates that at the present time eelgrass is the most important single food item to the waterfowl that pass through and winter in Humboldt Bay. From a management standpoint there is probably little that can be done to increase the production of eelgrass in this bay, however, the present eelgrass beds should be protected from future damage. Excess siltation, pollution, or certain oyster culture practices could reduce greatly the amount of eelgrass available to waterfowl (Keller, 1960).

SUMMARY

In order to determine the relative importance of various food items to the total waterfowl population of the Humboldt Bay area, food habits and abundance of each species of waterfowl were correlated. Eelgrass, unidentified vegetation, clams, barley, clover, creeping spike rush, prairie bulrush, and widgeon grass, in order of importance, accounted for 94.6 percent of the volume indices. This indicated that at the present time eelgrass is the most important waterfowl food item in the Humboldt Bay area.

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APPENDIX

TABLE A-1

Food of Eleven Species of Waterfowl, Humboldt Bay, California

Food items	Frequency	Percent of frequency	Frequency rate	Volume	Percent of total volume	Volume rate
PINTAIL (49) 15.6% of population						
PLANT FOOD						
Hordeum vulgare Barley	10	20.4	318.2	12.4	25.2	392.4
Scirpus paludosus Prairie Bulrush	16	32.6	508.6	7.3	14.8	230.7
Eleocharis macrostachya Creeping Spike Rush	24	49.0	764.4	2.4	4.8	75.1
Ruppia maritima Widgeon Grass	5	10.2	159.1	2.3	4.7	73.2
Distichlis spicata Salt Grass	3	6.1	95.2	.4	.8	13.0
Rosa sp. Rose	3	6.1	95.2	.2	.4	6.7
Zostera marina (vegetation) Eelgrass	1	2.0	31.2	.2	.4	6.3
Plantago sp. Plantain	1	2.0	31.2	.1	.2	3.2
Sparganium eurycarpum Broad-Fruited Bur Reed	1	2.0	31.2	.1	.2	3.2
Scirpus americanus Three Square	2	4.1	64.0	.1	.1	1.7
Potamogeton sp. Pondweed	10	20.4	318.2	*trace	.1	1.6
Sparganium sp. Bur Reed	3	6.1	95.2	trace	trace	.5
Polygonum persicaria Lady's-thumb	3	6.1	95.2	trace	trace	.5
Potamogeton pectinatus Sago Pondweed	2	4.1	64.0	trace	trace	.3
Melilotus sp. Sweet Clover	2	4.1	64.0	trace	trace	.3
Galium sp.	2	4.1	64.0	trace	trace	.3
Carex obnupta Slough Sedge	1	2.0	31.2	trace	trace	.2
Scirpus sp. Bulrush	1	2.0	31.2	trace	trace	.2
Polygonum sp. Smartweed	1	2.0	31.2	trace	trace	.2
Rumex sp. Dock	1	2.0	31.2	trace	trace	.2
Ranunculus sp. Buttercup	1	2.0	31.2	trace	trace	.2
Cornus sp. Dogwood	1	2.0	31.2	trace	trace	.2
Hippuris vulgaris Mare's Tail	1	2.0	31.2	trace	trace	.2
Unidentified Vegetation	23	46.9	731.6	17.0	34.7	541.4
ANIMAL FOOD						
Unidentified Pelecypoda Clams	12	24.5	382.2	5.5	11.2	175.7
Unidentified Gastropoda Gastropods	4	8.2	127.9	.7	1.3	20.7
Unidentified Mollusca Mollusks	1	2.0	31.2	.4	.8	12.7
Unidentified Arthropoda Arthropod	1	2.0	31.2	trace	trace	.2
Total				42.9	98.7	

TABLE A-1—Continued

Food of Eleven Species of Waterfowl, Humboldt Bay, California

Food items	Frequency	Percent of frequency	Frequency rate	Volume	Percent of total volume	Volume rate
MALLARD (24) 0.3% of population						
PLANT FOOD						
Hordeum vulgare Barley	7	29.2	8.8	5.6	49.6	14.9
Potamogeton sp. Pondweed	11	45.8	13.7	1.6	13.9	4.2
Eleocharis macrostachya Creeping Spike Rush	14	58.3	17.5	.6	5.8	1.7
Scirpus paludosus Prairie Bulrush	4	16.7	5.0	.4	3.9	1.2
Carex obnupta Slough Sedge	1	4.2	1.3	.3	2.7	.8
Zostera marina (vegetation) Eelgrass	2	8.3	2.5	.3	2.2	.7
Hippuris vulgaris Mare's Tail	5	20.8	6.2	.3	2.2	.7
Polygonum sp. Smartweed	4	16.7	5.0	.2	1.8	.5
Ranunculus flabellaris Yellow Water Crowfoot	1	4.2	1.3	.2	1.8	.5
Polygonum persicaria Lady's thumb	3	12.5	3.8	.2	1.3	.4
Scirpus americanus Three Square	1	4.2	1.3	.2	1.3	.4
Sparganium sp. Bur Reed	3	12.5	3.8	.2	1.3	.4
Potamogeton pectinatus Sago Pondweed	2	8.3	2.5	.1	.9	.3
Anacharis sp. Waterweed	1	4.2	1.3	trace	.6	.2
Potamogeton natans Floating-Leaf Pondweed	1	4.2	1.3	trace	.4	.1
Zostera marina (seeds) Eelgrass	1	4.2	1.3	trace	trace	.01
Alopecurus sp. Foxtail	1	4.2	1.3	trace	trace	.01
Gramineae Unknown grass	1	4.2	1.3	trace	trace	.01
Polygonum natans Water persicaria	1	4.2	1.3	trace	trace	.01
Polygonum punctatum Dotted Smartweed	1	4.2	1.3	trace	trace	.01
Polygonum lapathifolium Pale persicaria	1	4.2	1.3	trace	trace	.01
Polygonum coccineum Swamp Knotweed	1	4.2	1.3	trace	trace	.01
Rumex sp. Dock	1	4.2	1.3	trace	trace	.01
Ranunculus sp. Buttercup	1	4.2	1.3	trace	trace	.01
Amaranthus sp. Amaranth	1	4.2	1.3	trace	trace	.01
Cirsium sp. Thistle	1	4.2	1.3	trace	trace	.01
Cornus sp. Dogwood	1	4.2	1.3	trace	trace	.01
Unidentified vegetation	6	25.0	7.5	.7	6.0	1.8

TABLE A-1—Continued

Food of Eleven Species of Waterfowl, Humboldt Bay, California

Food items	Frequency	Percent of frequency	Frequency rate	Volume	Percent of total volume	Volume rate
MALLARD (24)—Continued						
ANIMAL FOOD						
Insects						
Unidentified Insect	4	16.7	5.0	.2	1.8	.5
Pelecypoda						
Unidentified clams	2	8.3	2.5	.1	.9	.3
Gastropoda						
Unidentified gastropods	1	4.2	1.3	.1	.9	.3
Total				11.3	99.3	
GREEN-WINGED TEAL (50) .4% of population						
PLANT FOOD						
Eleocharis macrostachya						
Creeping Spike Rush	26	52.0	20.8	1.5	15.0	6.0
Ranunculus sp.						
Buttercup	5	10.0	4.0	.8	8.5	3.4
Scirpus paludosus						
Prairie Bulrush	19	38.0	15.2	.7	7.6	3.0
Triticum sp.						
Wheat	2	4.0	1.6	.5	5.2	2.1
Alopecurus sp.						
Foxtail	3	6.0	2.4	.4	4.3	1.7
Potamogeton pectinatus						
Sago pondweed	3	6.0	2.4	.2	2.4	1.0
Polygonum lapathifolium						
Pale persicaria	1	2.0	.8	.2	2.1	.8
Distichlis spicata						
Salt grass	6	12.0	4.8	trace	.3	.1
Ruppia maritima						
Widgeon Grass	6	12.0	4.8	trace	.3	.1
Carex obnupta						
Slough Sedge	5	10.0	4.0	trace	.3	1.0
Chenopodium sp.						
Goosefoot	2	4.0	1.6	trace	.1	.04
Carex sp.						
Sedge	2	4.0	1.6	trace	.1	.04
Sparganium sp.						
Bur Reed	2	4.0	1.6	trace	.1	.04
Scirpus validus						
American Great Bulrush	1	2.0	.8	trace	trace	.02
Polygonum persicaria						
Lady's Thumb	1	2.0	.8	trace	trace	.02
Polygonum hydropiper						
Water Pepper	1	2.0	.8	trace	trace	.02
Juncus sp.						
Rush	1	2.0	.8	trace	trace	.02
Melilotus sp.						
Sweet Clover	1	2.0	.8	trace	trace	.02
Hippuris vulgaris						
Mare's Tail	1	2.0	.8	trace	trace	.02
Unidentified Seed	1	2.0	.8	trace	trace	.02
Unidentified Vegetation	12	24.0	9.6	1.8	18.9	7.6
ANIMAL FOOD						
Gastropoda						
Unidentified gastropods	3	6.0	2.4	3.2	33.6	13.4
Mollusca						
Unidentified mollusks	5	10.0	4.0	trace	.3	.1
Unidentified animal matter	1	2.0	.8	trace	.5	.2
Total				9.3	99.5	

TABLE A-1—Continued

Food of Eleven Species of Waterfowl, Humboldt Bay, California

Food items	Frequency	Percent of frequency	Frequency rate	Volume	Percent of total volume	Volume rate
BALDPATE (140) 47.1% of population						
PLANT FOOD						
Zostera marina (Vegetation)						
Eelgrass	121	86.4	4,069.4	120.0	81.0	3,816.8
Trifolium sp. (Vegetation)						
Clover	9	6.4	301.4	8.9	6.0	282.7
Eleocharis macrostachya						
Creeping Spike Rush	39	27.9	1,314.1	5.2	3.5	161.1
Hippuris vulgaris						
Mare's Tail	5	3.6	169.6	1.5	1.2	48.3
Melilotus sp.						
Sweet Clover	2	1.4	65.9	1.2	.8	38.2
Sparganium sp.						
Bur Reed	2	1.4	65.9	.6	.4	10.2
Potamogeton pectinatus						
Sago Pondweed	5	3.6	169.6	.5	.3	14.6
Polygonum sp.						
Smartweed	1	.7	33.0	.4	.3	12.7
Potamogeton sp.						
Pondweed	6	4.3	202.5	.3	.2	8.8
Unidentified Grass blades	4	2.9	136.6	.2	.1	5.09
Scirpus paludosus						
Prairie Bulrush	6	4.3	202.5	trace	trace	.9
Distichlis spicata						
Salt Grass	3	2.1	98.9	trace	trace	.5
Scirpus acutus						
Viscid Bulrush	2	1.4	65.9	trace	trace	.3
Ranunculus sp.						
Buttercup	2	1.4	65.9	trace	trace	.3
Polygonum persicaria						
Lady's Thumb	1	.7	33.0	trace	trace	.1
Rumex sp.						
Dock	1	.7	33.0	trace	trace	.1
Amaranthus sp.						
Amaranth	1	.7	33.0	trace	trace	.1
Plantago sp.						
Plantain	1	.7	33.0	trace	trace	.1
Unidentified Seed	2	1.4	65.9	trace	trace	.3
Moss						
Unidentified	1	.7	33.0	trace	trace	.1
Unidentified Vegetation	45	32.1	1,511.9	8.8	5.9	279.6
ANIMAL FOOD						
Insecta						
Unidentified Insect	4	2.9	136.6	.5	.3	16.4
Gastropoda						
Unidentified Gastropod	1	.7	33.0	trace	trace	.1
Unidentified Animal Matter	1	.7	33.0	trace	trace	.1
Total				118.1	100.0	
CANVASBACK (17) 1.2% of population						
PLANT FOOD						
Potamogeton pectinatus						
Sago Pondweed	7	41.2	173.0	4.2	15.7	65.8
Ruppia maritima						
Widgeon Grass	3	17.6	73.9	.7	2.6	11.0
Potamogeton sp.						
Pondweed	1	5.9	21.8	trace	trace	.08
Zostera marina						
Eelgrass	1	5.9	21.8	trace	trace	.08

TABLE A-1—Continued

Food of Eleven Species of Waterfowl, Humboldt Bay, California

Food items	Frequency	Percent of frequency	Frequency rate	Volume	Percent of total volume	Volume rate
CANVASBACK (17)—Continued						
ANIMAL FOOD						
Pelecypoda						
Unidentified Clams	11	64.7	271.7	18.9	70.5	296.08
Macoma sp.						
(Clam)	1	5.9	24.8	3.0	11.2	47.0
Total				26.8	100.0	
LESSER SCAUP (13) .3% of population						
PLANT FOOD						
Triticum sp.						
Wheat	1	7.7	2.3	.5	4.6	1.4
Potamogeton sp.						
Pondweed	3	23.1	6.9	.1	.5	.2
Potamogeton pectinatus						
Sago Pondweed	2	15.4	4.6	trace	.2	.05
Eleocharis macrostachya						
Creeping Spike Rush	3	23.1	6.9	trace	.1	.04
Distichlis spicata						
Salt Grass	2	15.4	4.6	trace	.1	.03
Scirpus paludosus						
Prairie Bulrush	2	15.4	4.6	trace	.1	.03
Hippusus vulgaris						
Mare's Tail	2	15.4	4.6	trace	.1	.03
Sparganium sp.						
Bur Reed	1	7.7	2.3	trace	trace	.01
Sparganium eurycarpum						
Broad Fruited Bur Reed	1	7.7	2.3	trace	trace	.01
Ruppia maritima						
Widgeon Grass	1	7.7	2.3	trace	trace	.01
Scirpus acutus						
Viscid Bulrush	1	7.7	2.3	trace	trace	.01
Polygonum persicaria						
Lady's Thumb	1	7.7	2.3	trace	trace	.01
Ranunculus flabellaris						
Yellow Water Crowfoot	1	7.7	2.3	trace	trace	.01
Unidentified Seed	1	7.7	2.3	trace	trace	.01
Unidentified Vegetation	5	38.5	11.6	3.09	34.7	10.4
ANIMAL FOOD						
Macoma sp.						
Clam	1	7.7	2.3	5.0	45.5	13.7
Mollusca						
Unidentified Mollusk	1	7.7	2.3	1.0	9.1	2.7
Crustacea						
Unidentified Crustacian	2	15.4	4.6	.5	4.6	1.4
Gastropoda						
Unidentified Gastropod	1	7.7	2.3	trace	trace	.03
Total				10.1	99.6	
GREATER SCAUP (20) 2.3% of population						
PLANT FOOD						
Zostera marina						
Eelgrass	2	10.0	23.0	.6	4.4	10.2
Scirpus paludosus						
Prairie Bulrush	1	5.0	11.5	trace	trace	.2
ANIMAL FOOD						
Columbella carinata						
Gastropod	7	35.0	80.5	4.9	35.7	82.1

TABLE A-1—Continued

Food of Eleven Species of Waterfowl, Humboldt Bay, California

Food items	Frequency	Percent of frequency	Frequency rate	Volume	Percent of total volume	Volume rate
GREATER SCAUP (20)—Continued						
Pelecypoda						
Unidentified Clams	10	50.0	115.0	3.9	28.8	64.2
Nassarius mendicus						
Gastropod	3	15.0	34.5	.8	5.9	13.6
Macoma sp.						
Clam	3	15.0	34.5	1.9	14.0	32.2
Columbella aurantiaca						
Gastropod	2	10.0	23.0	.7	5.2	12.0
Mollusca						
Unidentified Mollusk	1	5.0	11.5	.4	2.9	6.8
Nassarius fossatus						
Gastropod	1	5.0	11.5	.4	2.9	6.8
Nassarius sp.						
Gastropod	1	5.0	11.5	trace	trace	.08
Lacuna sp.						
Gastropod	1	5.0	11.5	trace	trace	.08
Total				13.6	99.8	
BUFFLEHEAD (22) .7% of population						
PLANT FOOD						
Scirpus paludosus						
Prairie Bulrush	4	18.2	12.7	.3	5.1	3.5
Ruppia maritima						
Widgeon Grass	5	22.7	15.9	.1	1.9	1.3
Potamogeton pectinatus						
Sago Pondweed	3	13.6	9.5	.1	1.8	1.2
Potamogeton pectinatus						
Sago Pondweed Tubers	1	4.5	3.2	.1	1.6	1.1
Hippurus vulgaris						
Mare's Tail	2	9.1	6.4	trace	.2	.1
Potamogeton sp.						
Pondweed	2	9.1	6.4	trace	.2	.1
Circium sp.						
Thistle	2	9.1	6.4	trace	.2	.1
Sparganium sp.						
Bur Reed	2	9.1	6.4	trace	.2	.1
Sparganium eurycarpum						
Broad Fruited Bur Reed	1	4.5	3.2	trace	trace	.06
Trifolium sp.						
Clover	1	4.5	3.2	trace	trace	.06
Rosa sp.						
Rose	1	4.5	3.2	trace	trace	.06
Eleocharis macrostachya						
Creeping Spike Rush	1	4.5	3.2	trace	trace	.06
Unidentified Vegetation	1	4.5	3.2	trace	trace	.06
ANIMAL FOOD						
Hemiptera						
Unidentified Bug	4	18.2	12.7	1.6	25.7	18.0
Pelecypoda						
Unidentified Clams	7	31.8	22.3	1.1	17.5	12.2
Crustacea						
Unidentified Crab	5	22.7	15.9	1.0	15.3	10.7
Crustacea						
Unidentified Shrimp	4	18.2	12.7	.9	14.5	10.2
Lacuna sp.						
Gastropod	3	13.6	9.5	.6	9.6	6.7
Gastropoda						
Unidentified Gastropod	4	18.2	12.7	.2	3.5	2.4

TABLE A-1—Continued

Food of Eleven Species of Waterfowl, Humboldt Bay, California

Food items	Frequency	Percent of frequency	Frequency rate	Volume	Percent of total volume	Volume rate
BUFFLEHEAD (22)—Continued						
Odestomia sp. Gastropod	1	4.5	3.2	.1	1.6	1.1
Columbella aurantiaca Gastropod	1	4.5	3.2	trace	.8	.6
Columbella guspata Gastropod	1	4.5	3.2	trace	trace	.05
Total				6.1	99.7	
WHITE-WINGED SCOTER (17) .1% of population						
PLANT FOOD						
Ulva sp. Sea Lettuce	1	5.9	.6	trace	trace	.001
ANIMAL FOOD						
Pelecypoda Unidentified Clams	15	88.2	8.9	5.7	48.8	4.9
Nassarius mendicus Gastropod	8	47.1	4.7	4.6	17.4	1.7
Ostra sp. Oyster	1	5.9	.6	2.2	14.1	1.4
Crustacea Unidentified Crab	4	23.5	2.4	1.5	6.6	.7
Columbella aurantiaca Gastropod	2	11.8	1.2	1.2	4.6	.5
Columbella carinata Gastropod	7	41.2	4.1	1.0	3.6	.4
Olivella biplicata Olive Shell	2	11.8	1.2	.5	2.9	.3
Olivella pedroana Gastropod	1	5.9	.6	.1	1.5	.2
Columbella gauspata Gastropod	1	5.9	.6	trace	.3	.03
Nassarius fassatus Gastropod	1	5.9	.6	trace	trace	.001
Nassarius cooperi Gastropod	1	5.9	.6	trace	trace	.001
Littorina sp. Periwinkle	1	5.9	.6	trace	trace	.001
Total				17.7	99.8	
RUDDY DUCK (21) .1% of population						
PLANT FOOD						
Ruppia maritima Widgeon Grass	13	61.9	6.2	6.2	68.1	6.8
Potamogeton pectinatus Sago Pondweed	16	76.3	7.6	1.6	17.4	1.7
Potamogeton sp. Pondweed	2	9.5	.9	.3	3.3	.3
Potamogeton pectinatus Sago Pondweed tubers	1	4.8	.5	.2	1.6	.2
Scirpus paludosus Prairie Bulrush	3	14.3	1.4	.1	1.2	.1
Eleocharis macrostachya Creeping Spike Rush	4	19.0	1.9	.1	1.4	.1
Zostera marina Eelgrass	1	4.8	.5	.1	2.0	.1

TABLE A-1—Continued

Food of Eleven Species of Waterfowl, Humboldt Bay, California

Food items	Frequency	Percent of frequency	Frequency rate	Volume	Percent of total volume	Volume rate
RUDDY DUCK (21)—Continued						
Hippurus vulgaris						
Mare's Tail	2	9.5	1.0	trace	.1	.01
Scirpus americanus						
Three Square	1	4.8	.5	trace	trace	.005
Ranunculus sp.						
Buttercup	1	4.8	.5	trace	trace	.005
Circium sp.						
Thistle	1	4.8	.5	trace	trace	.005
ANIMAL FOOD						
Crustacea						
Unidentified shrimp	2	9.5	1.0	.5	5.5	.6
Total				9.1	100.6	
BLACK BRANT (20) 20.2% of population						
PLANT FOOD						
Zostera marina						
Eelgrass	16	80.0	1,616.0	18.2	81.3	1,643.129
Unidentified Vegetation	12	60.0	1,212.0	4.1	18.5	373.700
Salicornia ambigua						
Pickleweed	1	5.0	101.0	trace	trace	.444
Diatoms	2	10.0	202.0	trace	trace	.909
ANIMAL FOOD						
Crustacea						
Unidentified Crustacea	2	10.0	202.0	trace	trace	1.353
Gastropoda						
Egg cases	1	5.0	101.0	trace	trace	.444
Total				22.3	99.8	

* Values carried to three decimal places were used in calculating the frequency and volume rates.

TABLE A-2 *

Summation of Volume Indices

Food items	Percent of volume rates
Zostera marina Eelgrass	60.9
Unidentified Vegetation	13.5
Pelecypoda Unidentified Clams	6.1
Hordeum vulgare Barley	4.5
Trifolium sp. (vegetation) Clover	3.1
Eleocharis macrostachya Creeping Spike Rush	2.8
Scirpus paludosus Prairie Bulrush	2.7
Ruppia maritima Widgeon Grass	1.0
Potamogeton pectinatus Sago Pondweed	1.0
Macoma sp. Clam	.9
Hippuris vulgaris Mare's Tail	.6
Melilotus sp. Sweet Clover	.4
Gastropoda Unidentified Gastropods	.4
Sparganium sp. Bur Reed	.2
Hemiptera Unknown Bug	.2
Mollusca Unknown Mollusk	.2
Nassarius mendicus Gastropod	.2
Potamogeton sp. Pondweed	.2
Distichlis spicata Salt Grass	.2
Polygonum sp. Smartweed	.2
Columbella aurentiaca Gastropod	.1
Crustacea Shrimp	.1
Lacuna sp. Gastropod	.1
Nassarius fossatus Gastropod	.1
Rosa sp. Rose	.1
Graminae Unidentified Grass vegetation	.1
Ranunculus sp. Buttercup	.04
Triticum sp. Wheat	.04
Crustacea Unidentified	.03
Sparganium eurycarpum Broad Fruited Bur Reed	.02
Scirpus americanus Three-square	.02
Alopecurus sp. Foxtail	.02
Ostra sp. Oyster	.02
Polygonum persicaria Lady's Thumb	.01
Carex obnupta Slough Sedge	.01
Potamogeton pectinatus Sago Pondweed Tubers	.01
Scirpus sp. Bulrush	trace
Rumex sp. Dock	trace
Cornus sp. Dogwood	trace
Galium sp. Galium	trace
Ranunculus flabellaris Yellow Water Crowfoot	trace
Polygonum lapathifolium Pale Persicaria	trace
Anacharis sp. Waterweed	.2
Potamogeton natans Floating Leaf Pondweed	.2
Zostera marina (seed) Eelgrass	.2
Gramineae Unidentified Grass	.2
Polygonum punctatum Dotted Smartweed	.2
Polygonum coccineum Swamp Knotweed	.2
Amaranthus sp. Amaranth	.2
Circium sp. Thistle	.2
Chenopodium sp. Goosefoot	.2
Carex sp. Sedge	trace
Scirpus validus American Great Bulrush	trace
Polygonum hydropiper Water Pepper	trace
Juncus sp. Rush	trace
Scirpus acutus Viscid Bulrush	.4
Potamogeton pectinatus Tubers (Sago Pondweed)	.4
Salicornia ambigua vegetation (Pickleweed)	.6
Diatoms	1.1
Moss	.2
Ulva sp. Sea Lettuce	.2
Littorina sp. Periwinkle	.2
Arthropoda Unidentified Arthropod	.2
Unidentified Animal Matter	.2
Nassarius sp. Gastropod	.1
Columbella guspata Gastropod	.02
Columbella carniata	.03
Olivella biplicata Olive Shell	.03
Olivella pedroana Gastropod	.03
Nassarius cooperi Gastropod	.03

* Food items in the table arranged in order of frequency of occurrence.

KING SALMON SPAWNING STOCKS OF THE CALIFORNIA CENTRAL VALLEY, 1940-1959[1]

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INTRODUCTION

This paper lists the best available counts and estimates of the king salmon *Oncorhynchus tshawytscha* (Walbaum) spawning runs of the Sacramento-San Joaquin River system from 1940 to 1959.

The first serious effort to determine the size of salmon runs in the Central Valley came as a result of the proposed construction of Shasta Dam. Part of the information needed to evaluate the effects of this proposed project on the fisheries was a count of the salmon which would be blocked. The first count was made in 1937, and every year since then a count or estimate has been made in one or more Central Valley streams. Estimates of the total fall run in all Central Valley streams did not start until much later. Almost all the counts given in the accompanying tables were made by the California Department of Fish and Game or the U. S. Fish and Wildlife Service. The only exceptions are the 1940-41 counts in the Sacramento River which were made by the U. S. Bureau of Reclamation.

Many counts and estimates were incomplete because counting had to be done at places where high water made it possible for fish to pass by uncounted, because fish counting weirs could not be kept fish tight, and because of the difficulty in seeing enough fish to make a satisfactory estimate possible in some of the larger streams. In addition, most of the earlier counts were made by men who had done little or no work with salmon. These men learned as they worked, but at first they did not fully appreciate how many salmon will go through a small hole in a counting weir, or how small a percent of the fish can actually be seen even in a stream where visibility seems excellent. This inevitably led to estimates which were too low—sometimes ridiculously low. In general the larger the stream the worse the difficulties of this type. For such reasons, during the 1940's, some of the estimates on the tributary streams and all of the totals on the main stem of the Sacramento were probably much too low. By way of contrast: On the tributaries the actual counts (other than incomplete counts) are reasonably accurate whenever and wherever listed, but are minimal rather than maximal.

Counting of salmon is relatively simple *only* where the entire spawning run can be forced to pass through a counting gate such as can be

[1] Submitted for publication May, 1960. Map by Cliffa Corson.

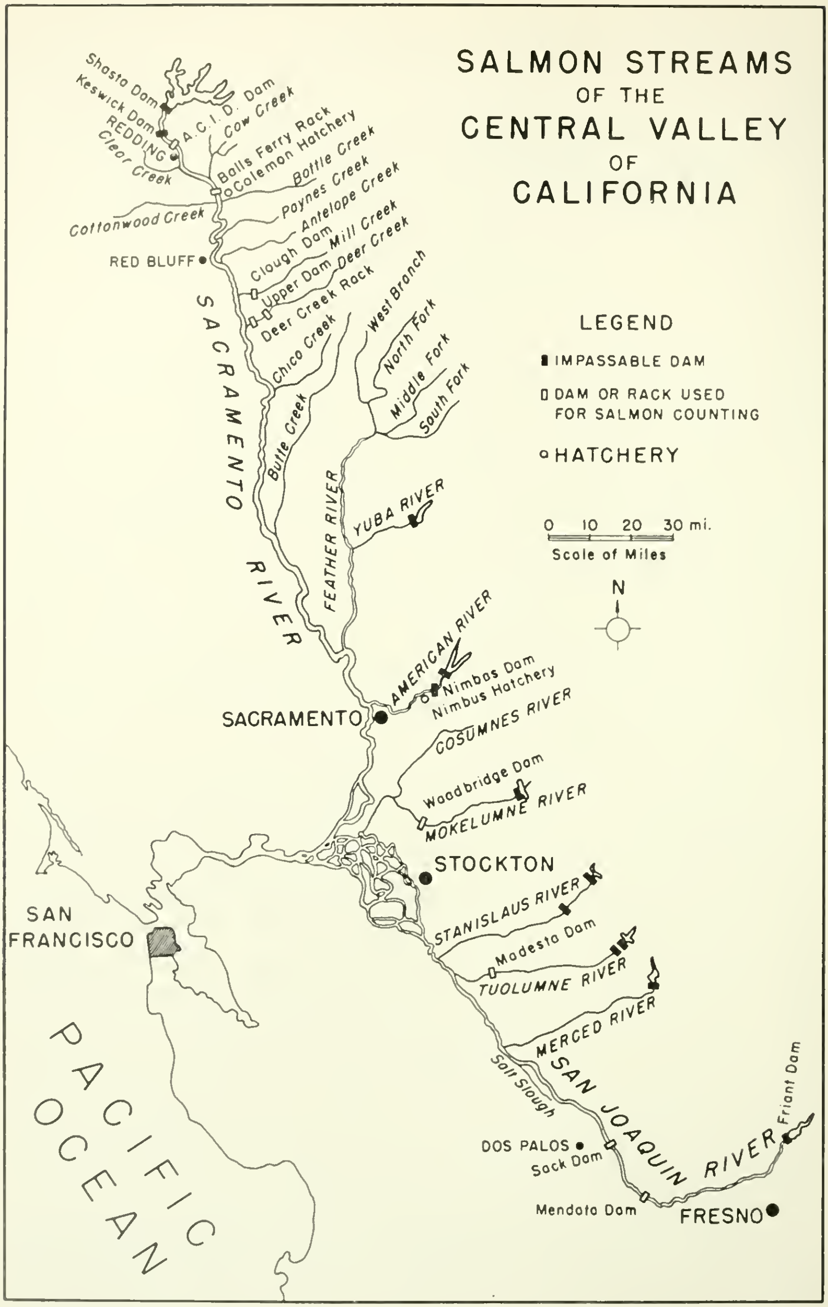

FIGURE 1. Salmon streams of the Central Valley. Only those streams and counting stations mentioned in the text are shown here. Dams with fishways are shown if mentioned in the text.

placed in a fishway over an otherwise impassable barrier. In the Central Valley no major run can be counted this easily.

For want of better places, much counting has been done at dams which have spawning area below them. Such counts are incomplete and must be supplemented with an estimate of the fish spawning downstream from the dam if a true idea of the entire spawning run is to be obtained. Often no satisfactory estimate could be made.

A good many of the earlier counts were made by the use of fish counting weirs or racks. These are structures which strain the water of the stream while, in theory, permitting the fish to go upstream only through counting gates. The more expensive ones used parallel lengths of pipe set close enough together to block the salmon, somewhat cheaper ones were wooden, and the cheapest of all were constructed of wire mesh. None proved satisfactory. Floods topped them or scoured holes underneath them, or the fish found or made small openings which they used in preference to the counting gates. One counter at such a place gave up trying to mend all the holes, closed down his counting gate, and counted the fish through the opening they seemed to like best.

Some of the runs have been calculated by the use of tag and recovery methods. For this type of study fish should be caught and tagged near the downstream end of a spawning area, then released and allowed to spawn naturally. After the fish have spawned and died the ratio of tagged to untagged fish is determined. To use a simplified example: If 500 tagged fish have been released in the stream and one out of ten spawned-out carcasses is tagged, it is assumed that the run is approximately 5,000 fish. This method has worked quite satisfactorily on the American and Stanislaus Rivers. It has proven much less satisfactory on the main stem of the Sacramento,[2] but nonetheless it has been the best available source of information on the main stream for several years.

The tag and recovery method has proven quite valuable as a method of training personnel to estimate the size of the run in a stream. After a man has learned from a tagging experiment about what proportion of the fish he can expect to see under certain conditions, he is then much better able to estimate the size of a run in a stream where no tagging has been done. Most of the Department of Fish and Game estimates were made by counting spawned-out carcasses and estimating the percent which the crew could be expected to find.

Another method of estimating involves aerial redd (nest) counts. There are difficulties such as those caused by many fish spawning so close together that the nests cannot be separated, but in streams where the bottom can be clearly seen the method should have good possibilities. Unfortunately, it has not yet been possible to check aerial redd counts against a fish ladder count.

Occasionally more than one estimate has appeared for a single stream for one year. One reason for this was that the Department of

[2] There are several reasons why tag and recovery methods have not yet been made satisfactory on the main stem of the Sacramento. Probably the most important has been the difficulty of recovering adequate numbers of spawned-out tagged carcasses in the main stem because of deep and murky water; the tagging site was only a few miles above the mouth of the Feather and was too far downstream; and the cylindrical wire traps used for catching the fish selected much too high a proportion of small salmon.

Fish and Game and the U.S. Fish and Wildlife Service sometimes made separate estimates. Both organizations have revised some estimates. In general the writer has used the Fish and Game estimate or the revised estimate when the above choices presented themselves. With some of the older material it was not possible to determine which was the revision. In such instances earlier and later runs and those in neighboring streams were considered and the more plausible figure used.

SALMON RUNS

In the Central Valley the king salmon is the only native salmon of any importance [3] but there are three basically different runs of kings.

Fall Run

Fall run fish enter the streams in the fall or winter and usually spawn within a few weeks of their arrival at the spawning grounds. More than 80 percent of the Central Valley salmon are of this type. Many streams have only a fall run. There is considerable variation in the timing of the runs in the different valley streams. Fall run salmon bound for the main stem of the Sacramento start through the delta in numbers in late August, reach peak numbers in late September, and a few are still going upstream in January. In general the Sacramento tributary runs start somewhat later; the bulk of the fish enter the tributaries in October, but as in the main stem a few are still going upstream in January. In some of the San Joaquin tributaries a lack of water may delay the run until December.

Spring Run

Spring run salmon enter the streams in the spring, spend the summer in the deeper holes, and spawn in the fall. They can survive only where there are relatively low summer temperatures.

On some streams, dams and diversions have greatly reduced the summer flow; this in turn has resulted in high summer temperatures and has almost or entirely eliminated the spring run without seriously damaging the fall run. The fall run enters these same streams after the temperature has dropped and the flow increased. The Tuolumne and Stanislaus Rivers are examples.

In general the spring run starts through the Sacramento-San Joaquin Delta in March, peaks there in May, and drops off rapidly in June. The fish go upstream rather slowly and are available to fishermen all summer in the upper Sacramento.

In the Central Valley spring run salmon are less numerous than those of the fall run. Counts and estimates are given in Table 4. In the early 1940's the most important spring run was probably that of the San Joaquin River. The run in this stream was eliminated by the drying up of the river below Sack Dam, near Dos Palos, after Friant Dam went into full operation.

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[3] Silver salmon *(Oncorhynchus kisutch)* have been introduced into the Sacramento system (but not into the San Joaquin). They seem to be doing well. Kokanee *(O. nerka kennerlyi)* have been planted above Shasta Dam and are abundant in the lake. Besides these introduced forms the Sacramento system has vestigial runs of pink *(O. gorbuscha)* and chum *(O. keta)* salmon. A few stray sockeye *(O. nerka nerka)* have been taken.

The Sacramento River now has the largest spring run. For the past few seasons no effort has been made to estimate the size of this run; to do so would be a major undertaking.

The spring runs listed are not complete. As with fall run fish, there are some very small runs, often in hard-to-reach places, which could not be checked without a larger staff.

Winter Run

Winter run fish are the least known and probably the least abundant of the Central Valley king salmon runs. True winter run fish enter the river in the winter and spawn early the following summer. The great majority spawns in the main stem of the Sacramento; small numbers enter some of the tributaries north of the Feather River. No estimates of their numbers have been made. In addition to the winter run fish there are some very late fall run fish which enter most of the Central Valley salmon streams in the winter and spawn almost immediately. In compiling the tables no attempt was made to separate the winter run or late fall run fish from those of the main fall run.

SALMON STREAMS

Comments on the individual streams of the Central Valley are given below; they are arranged from north to south.

Sacramento River

The Sacramento River is the largest and best salmon stream of the Central Valley. It is now blocked by Keswick Dam, but the spawning area that is still available is large and of good quality.

From 1937 through 1942 counts were made at the Anderson Cottonwood Irrigation District Dam at Redding. This is a low dam with removable flashboards which are seldom left in place during the entire run of salmon. There is a fishway past the dam. The 1937 count at this place was made by the California Division of Fish and Game. From 1938 through 1941 the counts were made by the U. S. Bureau of Reclamation, and in 1942 by the U. S. Fish and Wildlife Service.

The 1937-39 counts are not included in Table 1. They were 8,000 in 1937, 14,000 in 1938 and 22,000 in 1939. The 1939 count includes 6,000 spring run fish; the earlier counts were started after the spring run had passed. The count of 1939 is the only one of the six made at this point which appears to be complete, even for the fall run. It should be kept in mind that this counting station was upstream from almost all of the spawning area that is available to salmon today. The incomplete counts here range from 7,000 to 45,000.

From 1943 through 1945 counts on the main stream of the Sacramento were made at the Balls Ferry Rack which was three miles upstream from the mouth of Battle Creek. The rack was constructed for the purpose of counting fish, trapping them, and forcing part of the population to spawn downstream from the rack if there appeared to be danger of overcrowding in the area between Balls Ferry and Keswick Dam. The counts at Balls Ferry are incomplete. Many fish passed this rack uncounted during flood periods and many others found holes under it. Some salmon were trapped at Balls Ferry and transferred

to Coleman Hatchery. These fish are included only in the Balls Ferry count. It should be kept in mind that the counts made at Balls Ferry do not include the very substantial part of the run that spawns downstream from that point.

Balls Ferry Rack has not been used since 1945. From 1946 through 1956 the U. S. Fish and Wildlife Service made estimates of the fall and spring runs of the main stem of the Sacramento. Their estimates of the spring run are given in Table 4 for the entire period. Their estimates of the fall run are given only through 1949 (Table 1). From 1950 through 1959 the fall run estimates shown are those of the Department of Fish and Game.

The Fish and Wildlife Service estimates through 1952 were from ground level spawning area surveys. Aerial redd counts were started in January 1954 to check the estimate of the 1953 fall run and were used in making the surveys of the spring and fall runs of 1954, 1955, and 1956. These three surveys gave results which were 33 percent, 67 percent, and 46 percent of the Department of Fish and Game figures for the fall run in the same three years. The Department of Fish and Game used a tag and recovery method from 1950 through 1955 and has used spawning bed surveys since then. In six out of seven years when both organizations made estimates of the fall run, those of the Fish and Wildlife Service were lower; 1951 was the exception. A study to determine the reasons for the differences in the results obtained by the two organizations was planned but was not put into effect. Due to a lack of funds the Fish and Wildlife man in the area was transferred to another state.

Keswick Dam

Keswick Dam is located a few miles above Redding on the main stem of the Sacramento. It is a re-regulating dam used to smooth out the flow below Shasta Dam. No fish can pass Keswick Dam. Fish trapping facilities were installed there when the dam was built. The counts listed are of salmon actually trapped at Keswick. Most of them are hauled to Coleman Hatchery. In earlier years part of them were trucked to Deer Creek, and more recently some have been taken to Clear Creek.

The Keswick fish were divided into spring run and fall run; August 31st was arbitrarily selected as the last day of the spring run in this part of the river.

Because of a lack of spawning area between Redding and Keswick, the fish ladder at the A.C.I.D. Dam has been kept closed most of the time, and efforts have been made to limit the fish going past this point to a number which could be satisfactorily handled at Coleman Hatchery.

From 1937 through 1943 the counts covered only a part of the Sacramento River. Since 1944 counts plus estimates have included the entire river. Through 1949 the totals obtained (40,000 to 75,000 fish) are regarded as being too low. From 1950 through 1959 the totals have ranged from 408,000 in 1953 down to a disastrous low of 68,000 in 1957.

The spring run of parts of the Sacramento River was counted from 1939 through 1945. Spring run estimates of the entire river did not start until 1946. The last one was made in 1956. During these 11 years the estimates ranged from 5,000 in 1951 to 27,000 in 1946.

Battle Creek

Battle Creek is a salmon stream with good spawning areas and adequate water flows in its lower reaches. Starting a short distance above Coleman Hatchery, much of the stream is badly degraded by low flows resulting from power diversion.

Estimates of the spring and fall runs spawning naturally in Battle Creek were made by the U. S. Fish and Wildlife Service from 1946 through 1956. Starting in 1955 the California Department of Fish and Game has made estimates of the fall run.

Hatcheries

Two hatcheries have operated on Battle Creek. The old Battle Creek Hatchery operated through 1945. The newer and larger Coleman Hatchery has operated since 1943. The Battle Creek Hatchery took fall run fish from the natural run of Battle Creek. From 1943 through 1946 small numbers of spring run fish were trapped at Coleman Hatchery. In no instance did the number taken exceed 500. During this period Coleman Hatchery was obtaining a majority of its fish from Keswick Dam and from the Balls Ferry Racks. Not until 1946 did the Coleman Hatchery start taking fall run fish from Battle Creek. Since that time it has taken them every year.

The total run (hatchery take plus natural spawners) has averaged 15,000 fall run salmon per year since 1946, and has ranged from a low of 3,000 in 1948 to 30,000 in 1959. We cannot know how many fall run fish would be spawning in this stream if no hatchery were there.

The spring run is much smaller. In seven of the 11 years of record, the estimate was about 2,000 fish. In the other years runs were lower; in 1948 and 1949 they were below 500.

Mill Creek

For its size Mill Creek is a good salmon stream, but the fish are sometimes handicapped by low flows resulting from irrigation diversions.

From 1947 through 1952 the U.S. Fish and Wildlife Service estimated the number of fall spawners in Mill Creek from spawning area surveys. Since that time similar estimates have been made by the Department of Fish and Game.

From 1947 through 1953 the U.S. Fish and Wildlife service made estimates of the spring run in Mill Creek. Since that time a counting station has been set up at Clough Dam, and all fish passing over the dam have been counted by the Department of Fish and Game. Usually the bulk of the fall run spawns below Clough Dam; for all practical purposes the entire spring run goes upstream past the dam.

Since 1947 the fall run of Mill Creek has ranged from a high of 16,000 in 1952 to a low of 1,000 in 1956 and 1959. The spring run was about 3,000 in 1947, 1953, and 1955, and was down to less than 500 in 1951.

Deer Creek

Deer Creek is about five miles from Mill Creek, is about the same size, and suffers from the same fundamental trouble of low flows caused by irrigation diversions.

When plans were being made for the handling of Sacramento salmon blocked by the construction of Shasta and Keswick Dams, Deer Creek was selected as a place where spring run fish from Keswick could be transferred and allowed to spawn naturally. In order to determine the size of the natural run into Deer Creek, the U.S. Fish and Wildlife Service constructed a weir and set up a counting station at which spring run counts were made from 1941 through 1948. After that time the counting station was abandoned, and from 1949 through 1956 estimates were made of the Deer Creek run. Apparently the natural spring run was not increased by the addition of transfers from Keswick. No weir counts were made of the fall run. The U.S. Fish and Wildlife Service estimated the size of the fall run from 1947 through 1953. The fall run estimates during the next three years were joint ventures involving both Federal and State men. Since that time estimates of the fall run (but not the spring run) have been made by the Department of Fish and Game.

Since 1947 the largest fall run was 12,000 fish in 1952, and there were five years when the run dropped below 500. The highest spring run on record was 4,000 in 1946; in 1940 it was below 500.

Chico Creek

The fall run of Chico Creek was estimated as 50 fish in 1957, and the spring run as 1,000 in 1958 and 200 in 1959. It appears that no other estimates have been made. The 1957 fall run was included under "Miscellaneous Small Streams." An additional 15 miles of spawning area was opened on Chico Creek during the summer of 1958 by the removal of a barrier.

Butte Creek

Butte Creek, unlike the majority of the small streams of the northern Sacramento Valley, has a spring run but almost no fall run. There are numerous removable dams on Butte Creek which are left in place so late that the fall run has little chance to get past them. Some of these diversions are for duck clubs. Fishways have improved conditions somewhat, but the fall run has not built up.

The spring run has ranged from 3,000 fish in 1956 down to less than 500 in 1953 and 1959.

Miscellaneous Small Tributaries of the Upper Sacramento River

Included under this heading are Antelope Creek, Clear Creek, Cottonwood Creek, Cow Creek, Paynes Creek, and about a dozen other streams which may have fall runs when the fall rains are early and heavy. Some of the streams have spring runs. The fall runs were estimated by the U.S. Fish and Wildlife Service from 1947 through 1953, by a joint venture through 1956, and since that time by the Department of Fish and Game. The survey of these minor streams is more complete now than it was in former years.

Since 1947 the largest fall run in all of these streams combined was 13,000 fish in 1953. It was down to 1,000 in 1948 and 1949. The spring run totals in the only three years of record were under 500 fish twice, and once (1956) reached 1,000 fish.

Feather River

The Feather River is the largest tributary of the Sacramento below Shasta Dam. Dams and diversions have worsened conditions for the salmon—especially the spring run. In spite of this the Feather is still a good salmon stream. There are runs which spawn in the main stream, the North Fork, the West Branch of the North Fork, the Middle Fork, and the South Fork. The majority of the fish enter in the fall; the largest part of this run spawns in the main stream. The majority of the spring run fish spawn in the Middle Fork, with a few in the North Fork, South Fork, and West Branch.

The U.S. Fish and Wildlife Service made an estimate of the spring and fall runs in 1946. The men who did the work were not experienced at making estimates on the spawning grounds, and after considering their counts of spawning and dead fish it is the belief of the department that this estimate represents only a small part of the fish that entered the Feather that year. Since 1953 the Department of Fish and Game has estimated the size of the fall run from spawning area surveys. In 1958 and 1959 this was supplemented with aerial redd counts. The spring run was also estimated in 1958 and 1959.

The highest fall run was 86,000 in 1955. The low year was 1957 with 10,000 fish. Estimates of the spring run have ranged from 4,000 in 1959 down to 1,000 in 1955 and 1957.

Yuba River

For many years the Yuba River was seriously handicapped by a diversion dam below which there was often very little water and over which there was no functional fish ladder. Upstream migrants could pass only during very high flows. There are now two good fish ladders, one at each end of this dam, but the water problem still remains.

The fall runs in the Yuba have been estimated by the Department of Fish and Game since 1953. They ranged from a high of 10,000 in 1959 to a low of 1,000 in 1957.

The Yuba is known to have had a spring run but no estimate of its size has been made. This run has virtually disappeared.

American River

The American River formerly had a partial block at the old Folsom power dam over which there was a fishway. More recently it has been totally blocked by a dam at Nimbus. Spawning grounds below Folsom were quite extensive, but the new Nimbus Dam has cut off the grounds which were formerly used by over two-thirds of the fish. The new Folsom Dam has created some temperature problems which adversely affect the Nimbus salmon hatchery and the salmon spawning naturally in the River below.

Counts were made by the Department of Fish and Game of the runs into the American River in 1941 and 1942, but due to early floods these counts were so incomplete that they have not been included in the tables. Tagging experiments were conducted from 1943 through 1946. The 1943 experiment was not completed and results were not included in the tables. From 1948 on, estimates of the size of the American River run have been made by the department. The one exception was in 1950 when an early flood made an estimate impossible. Since 1955

fish taken at the recently constructed Nimbus Hatchery are also included in the tables. At least through 1951 there was a small spring run in the American, but at spawning time these fish became so mixed with those of the much larger fall run that it was impossible to separate them. The highest total run recorded on the American River was 39,000 in 1945. The lowest was 6,000 in 1956.

Cosumnes River

Parts of the Cosumnes River often have little or no flowing water until late fall or winter. Nature is responsible for most of this difficulty, but man contributes.

This stream has a late fall run and no spring run. A partial count was made by the Department of Fish and Game in 1941. Estimates were made by the department in 1953, and during each year since then. The highest estimate was 5,000 in 1954. The lowest was below 500 in 1959.

Mokelumne River

The Mokelumne River salmon runs have been greatly reduced by man's activities. Below Woodbridge Dam there is often too little water for the passage of salmon; for many years the dam itself was a serious fish block; industrial and mining pollution have, at times, been very serious. The stream has a fall run, but the spring run appears to be practically extinct.

All counts were made by the Department of Fish and Game, and all were made at Woodbridge Dam, which is located below all spawning areas. Partial counts were made in 1940, 1941, and 1942; complete counts in most of the following years. Woodbridge Dam has removable flashboards, but a good count can be made there in most seasons.

In both 1941 and 1942, incomplete counts gave 12,000 fish. In no other year have the counts—complete or incomplete—approached this figure. In 1948 and 1956, less than 500 fish passed Woodbridge Dam.

Stanislaus River

The Stanislaus River is a good fall run stream for its size but has almost no remaining spring run. A diversion dam (Goodwin Dam) blocks all salmon, and summer flows below it are low and warm. In the fall and winter, its waters are used for power generation and fluctuate violently.

All counts and estimates were made by the Department of Fish and Game. In 1940 and 1941 the counts were made at lightly constructed weirs and were not complete. Successful tag and recovery experiments were conducted in 1947 and 1948. Estimates were made during most of the following years. The highest estimate was 35,000 in 1953; the lowest (except for incomplete counts) was 4,000 in 1951, 1957, and 1959.

Tuolumne River

In some years the Tuolumne River has had fall runs which were larger than those of any Central Valley stream except the Sacramento. It has almost no spring run because its summer flows are low and warm, and fish cannot get past the La Grange Dam. Like the Stanislaus, the Tuolumne is used for power generation after the irrigation season is over, but its flows are larger and more stable.

Counts were made by the Department of Fish and Game at the Modesto Dam fish ladder in 1940, 1941, 1942, and 1944. The 1941 count was incomplete. In the other years, the dam was left in and counting continued until the run had dwindled away to almost nothing, then the flashboards were removed for safety reasons. The U.S. Fish and Wildlife Service made a count at the same place in 1946. This dam was condemned, and since 1947 it has been necessary to rely on estimates, all of which were made by the Department of Fish and Game. The biggest run of record was 130,000 in 1944; the smallest was 3,000 in 1951.

Merced River

Due to irrigation diversions, the Merced River is at present a marginal salmon stream. There is a lack of water at critical times of the year.

This stream has a poor fall run and poor spring run. No numerical estimate has been made of the spring run. All fall run counts and estimates were made by the Department of Fish and Game. Incomplete counts were made in 1940 and 1941. Estimates have been made every year since 1953. Since 1953 the highest estimate has been 4,000 fish in 1954. In all other years it has been below 500.

San Joaquin River

In the period under discussion this stream at first had an excellent spring run and a small fall run. Diversion of the San Joaquin at Friant Dam resulted in the drying up of the stream below the Sack Dam and in the virtually complete loss of both the spring and fall runs since 1949. All counts were made by the Department of Fish and Game, and all except those of 1948 and 1950 were made at the Mendota Dam which is well below all spawning areas. In 1948 about 2,000 salmon were trucked to a canal which led them around the dry area below the Sack Dam. The count was made as the fish left the truck. The 1950 count was made at a temporary fish ladder on Salt Slough. The ladder was built to lead salmon from the slough into a canal from which they could re-enter the river above the dry section of streambed. Only 36 fish used the ladder.

For all practical purposes, there has been no run since 1948. The highest run of record was 56,000 in 1945.

EXPLANATION OF TABLES

Counts

Few of the counts made in the Central Valley are truly complete because they were made at counting weirs which were not entirely fish tight, at low dams which some of the fish could jump uncounted, or at removable dams which had to be taken down before the run was entirely over. When it is believed that the great majority of the fish were counted, the figures used in the accompanying tables are referred to as a "count." The counts (and incomplete counts) do not include any fish which spawned downstream from the counting station.

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TABLE 1

Fall Run—King Salmon Spawning Stocks Upper Sacramento Valley, 1940-1959
(in thousands of fish)

Year	Sacramento River			Battle Creek			Mill Creek					
	Below Keswick Dam	Trapped at Keswick Dam	Total	Natural spawners	Hatchery	Total	Below Clough Dam	Above Clough Dam	Total	Deer Creek	Misc. small tribs.	Total Upper Sacto. Valley
1940	29[a]	--	29	--	4[d]							
41	30[a]	--	30	--	3[d]							
42	1[a]	--	4	--	3[d]							
43	35[b]	1[c]	36	--	2[d]							
44	73[b] plus [c]*	-	73	--	3[d]							
1945	52[b] plus [c]*	–[c]	52	--	3[d]							
46	40[c]*	9[c]	49	10[e]	7[d]	17						
47	75[c]*	--	75	7[e]	9[d]	16	--	--	[e]6	4[e]	6[e]	
48	40[c]*	–[c]	40	1[e]	2[d]	3	--	--	[e]4	1[e]	1[e]	
49	50[c]*		50	2[e]	5[d]	7	--	--	[e]2	–[e]	1[e]	
1950	110[f]	1[c]	111	–[e]	4[d]	4	--	--	[e]2	–[e]	2[e]	
51	70[f]	3[c]	73	4[e]	10[d]	14	--		[e]9	3[e]	4[e]	
52	260[f]	7[c]	267	4[e]	11[d]	15	12[e]	4[e]	16	12[e]	3[e]	313
53	400[f]	8[c]	408	4[e]	12[d]	16	6[g]	4[h]	10	4[e]	13[e]	451
54	270[f]	6[c]	276	4[e]	8[d]	12	4[g]	3[h]	7	3[g, e]	12[g, e]	310
1955	225[f]	6[c]	231	16[g]	10[d]	26	1[g]	2[h]	3	–[g, e]	1[g, e]	264
56	91[g]	3[c]	94	14[g]	7[d]	21	–[g]	–[h]	1	–[g, e]	8[g, e]	124
57	60[g]	8[c]	68	2[g]	3[d]	5	4[g]	1[h]	5	2[g]	3[g]	83
58	120[g]	8[c]	128	14[g]	15[d]	29	3[g]	1[h]	4	1[g]	8[g]	170
59	260[g]	7[c]	267	19[g]	11[d]	30	1[g]	–[h]	1	–[g]	6[g]	304

NOTES: – Signifies 500 fish or less.

[a] Incomplete counts made at Anderson Cottonwood Irrigation District Dam at Redding by U. S. Bureau of Reclamation in 1949-41, and by U. S. Fish & Wildlife Service in 1942. Most Sacramento salmon spawn below this point.

[b] Incomplete counts made at Balls Ferry counting rack by the U. S. Fish & Wildlife Service. Includes fish transferred from Balls Ferry to Coleman Hatchery. A large part of the run spawns below Balls Ferry.

[c] Count by U. S. Fish & Wildlife Service.

[d] Battle Creek fish taken at old Battle Creek Hatchery, 1940-1945, and at Coleman Hatchery 1946-1959.

[e] Estimate by U. S. Fish & Wildlife Service based on spawning area surveys and/or aerial redd counts.

[f] Calculation by California Department of Fish and Game based on tag recoveries.

[g] Estimate by California Department of Fish and Game based on spawning area surveys.

[h] Count by California Department of Fish and Game.

* The Department believes these estimates are too low.

TABLE 2

Fall Run—King Salmon Spawning Stocks Lower Sacramento Valley, 1940-1959
(in thousands of fish)

Year	Feather River and tributaries	Yuba River	American River			Total Lower Sacramento Valley	Total Sacramento Valley (upper and lower)
			Natural spawners	Nimbus Hatchery	Total		
1940							
41							
42							
43							
44	--	--	31 [f, i]		31		
1945	--	--	39 [f, i]	--	39		
46	11 [e] plus [c]*	--	38 [f, i]	--	38		
47							
48	--	--	15 [g]	--	15		
49	--	--	12 [g]	--	12		
1950	Early flood. No complete counts or estimates possible from Feather River south.						
51	--	--	22 [g]	--	22		
52	--	--	25 [g]	--	25		
53	28 [g]	6 [g]	28 [g]	--	28	62	513
54	68 [g]	5 [g]	29 [g]	--	29	102	412
1955	86 [g]	2 [g]	9 [g]	8 [h]	17	105	369
56	18 [g]	5 [g]	4 [g]	2 [h]	6	29	153
57	10 [g]	1 [g]	7 [g]	1 [h]	8	19	102
58	32 [g]	8 [g]	17 [g]	10 [h]	27	67	237
59	76 [g]	10 [g]**	18 [g]	13 [h]	31	117	421

NOTES: [c] Count by U. S. Fish & Wildlife Service.
[e] Estimate by U. S. Fish & Wildlife Service based on spawning area surveys and/or aerial redd counts.
[f] Calculation by California Department of Fish and Game based on tag recoveries.
[g] Estimate by California Department of Fish and Game based on spawning area surveys (supplemented by aerial redd counts on the Feather River in 1958 and 1959).
[h] Count by California Department of Fish and Game.
[i] Includes a small but unknown proportion of spring run fish.
* This published estimate is regarded as unrealistically low. The data on which it was based would make a total of 50,000 far more probable.
** Includes 3,500 fish which died unspawned when part of the river dried up.

TABLE 3

Fall Run—King Salmon Spawning Stocks San Joaquin Valley Streams, 1940-1959
(Including the Cosumnes and Mokelumne Rivers)
(in thousands of fish)

Year	Cosumnes River	Mokelumne River Woodbridge Dam	Stanislaus River	Tuolumne River	Merced River	Total San Joaquin Valley	Grand Total Central Valley
1940		5[j]	3[j]	122[h]	1[j]	131	
41	1[j]	12[j]	1[j]	27[j]	1[j]	42	
42	--	12[j]	--	44[h]			
43							
44	--	--	--	130[h]			
1945	--	6[h]					
46	--	--	--	61[c]			
47	--	--	13[f]	50[g]			
48	--	–[h]	15[f]	40[g]			
49	--	1[h]	8[g]	30[g]			
1950	Early flood. No complete counts or estimates possible.						
51	--	2[h]	4[g]	3[g]			
52	--	2[h]	10[g]	10[g]			
53	2[g]	2[h]	35[g]	45[g]	–[g]	84	597
54	5[g]	4[h]	22[g]	40[g]	4[g]	75	487
1955	2[g]	2[h]	7[g]	20[g]	–[g]	31	400
56	1[g]	–[h]	5[g]	6[g]	–[g]	12	165
57	1[g]	2[h]	4[g]	8[g]	[g]	15	117
58	1[g]	7[h]	6[g]	32[g]	–[g]	46	283
59	–[g]	2[h]	4[g]	46[g]	–[g]	52	473

NOTES: - Signifies 500 fish or less.
[c] Count by U. S. Fish & Wildlife Service.
[f] Estimate by California Department of Fish and Game based on tag recoveries.
[g] Estimate by California Department of Fish and Game based on spawning area surveys.
[h] Count by California Department of Fish and Game.
[j] Incomplete count by California Department of Fish and Game.

TABLE 4

Spring Run—King Salmon Spawning Stocks Sacramento-San Joaquin Valley, 1940-1959
(in thousands of fish)

Year	Sacramento River			Battle Creek			Mill Creek	Deer Creek	Chico Creek	Butte Creek	Feather River	Misc. small tribs.	San Joaquin River
	Below Keswick	Keswick Dam	Total	Coleman Hatchery	Natural spawners	Total							
1940	--	--	[a]11	--	--	--	--	–[k]					
41	--	--	[a]15	--	--	--	--	1[k]					
42	--	--	[a]3	--	--	--	--	1[k]					
43	--	6[c]	6	–[c]	--	--	--	1[k]	--	--	--	--	35[g]
44	10[b]	2[c]	12	–[c]		--	--	3[k]	--	--	--	--	5[h]
1945	3[b]	1[c]	4	–[c]	--	--	--	3[k]	--	--	--	--	56[h]
46	26[e]	1[c]	27	–[c]	2[e]	2	--	4[k]	--	--	2[e]	--	30[h]
47	25[e]	--	25	--	1[e]	1	3[e]	3[k]	--	--	--	--	6[h]
48	9[e]	--	9	--	–[e]	–	2[e]	2[k] plus[e]	--	--	--	--	2[h]
49	7[e]	--	7	--	–[e]	–	1[e]	1[e]					
1950	18[e]	--	18	--	1[e]	1	2[e]	2[e]	--	--	--	--	–[h]
51	5[e]	--	5	--	2[e]	2	–[e]	2[e]					
52	7[e]	--	7	--	2[e]	2	2[e]	2[e]					
53	8[e]	--	8	--	2[e]	2	3[e]	2[e]		–[g]			
54	9[e]	--	9	--	2[e]	2	2[h]	2[e]	--	--	3[g]	–[e]	
1955	17[e]	--	17	--	2[e]	2	3[h]	3[e]	--	--	1[g]	–[e]	
56	7[e]	--	7	--	2[e]	2	2[h]	3[e]	--	3[g]	2[g]	1[e]	
57	--	--	--	--	--	--	1[h]	--	--	2[g]	1[g]		
58	--	--	--	--	--	--	2[h]	--	1[g]	1[g]	3[g, m]		
59	--	--	--	--	--	--	2[h]	--	–[g]	–[g]	4[g, m]		

NOTES: - Signifies 500 fish or less.
[a] Incomplete counts made at Anderson Cottonwood Irrigation District Dam at Redding by U. S. Bureau of Reclamation in 1940-41, and by the U. S. Fish & Wildlife Service in 1942.
[b] Incomplete counts made at Balls Ferry counting rack by the U. S. Fish & Wildlife Service. Includes fish transferred from Balls Ferry to Coleman Hatchery.
[c] Count by U. S. Fish & Wildlife Service.
[e] Estimate by U. S. Fish & Wildlife Service based on spawning area surveys and/or aerial redd counts.
[g] Estimate by California Department of Fish and Game based on spawning area surveys and/or aerial redd counts.
[h] Count by California Department of Fish and Game.
[k] Incomplete count by U. S. Fish & Wildlife Service made at counting racks on Deer Creek (1940 count at upper Deer Creek diversion dam).
[m] This may include some fall run fish.

Incomplete Counts

In many instances the proportion of the run which got past the counting station unrecorded was known or suspected to be quite large. Such figures are referred to as "incomplete counts."

Fish Taken at a Hatchery or a Trapping Station

These figures refer only to salmon actualy taken by the hatchery crew. At times some of these fish were transferred to another stream. The counts of such fish are included with those of the stream where they were caught, *not* where they were released.

Calculations Based on Tag Recoveries

The accuracy of this method of population estimation depends on many factors. On the American and Stanislaus Rivers the results were satisfactory. On the Sacramento there were many difficulties and the figures obtained are only rough approximations.

Estimates from Spawning Bed Surveys

These estimates are made by counting spawning salmon and or spawned out carcasses, and basing the estimate of the size of the run on these figures. Inexperienced men have shown a tendency to make estimates that are far too low.

Estimates from Aerial Redd Counts

An airplane is flown over the stream, the salmon nests are counted or estimated, and an estimate of the run is based on this figure. Various complicating factors make the method less simple and reliable than it might seem.

SUMMARY

The fish counts of Central Valley salmon were started in 1937 as a result of the plans to build Shasta Dam. Enumeration has been by the California Department of Fish and Game, the U. S. Fish and Wildlife Service, and (less extensively) by the U. S. Bureau of Reclamation. Methods used have included fish ladder counts, fish weir counts, estimates of spawners, tag and recovery calculations, and (more recently) redd counts from the air. Many counts have been incomplete because counting weirs could not be kept fish-tight or were washed out by floods. In the early years most help was relatively inexperienced and gave estimates which were too low. Tag and recovery calculations gave satisfactory results on the American and Stanislaus rivers, but results on the upper Sacramento River have been much less satisfactory. Aerial redd counts seem to have possibilities but have not yet been standardized against fish ladder counts.

Because of a lack of manpower the earlier counts covered only limited areas; not until 1953 was an estimate made which covered the fall run of the entire Central Valley. Counts of the much smaller spring run have never covered the entire valley.

The king salmon is the only salmon of any importance in the Central Valley. Some silver salmon have recently been introduced in the Sacramento River, and some kokanee above Shasta Dam. King salmon are of three types: Fall run which enter in the fall or winter and spawn soon

after arrival; spring run which enter in the spring but do not spawn until fall; and winter run which enter in the late winter and spawn in early summer. Fall run fish are the most numerous and are found in most of the salmon streams. Spring run fish are kept separate in the counts; they are found in fewer streams and are much less numerous in total. Winter run fish are the least numerous and are confined to the upper Sacramento Valley. They are included with the fall run fish. The largest spring run may have been that of the San Joaquin River; it has been eliminated by the total diversion of the river since construction of Friant Dam and its attendant canal systems.

The largest fall run has been that of the Sacramento River which since 1953 has been estimated to have runs as high as 408,000 (1953) and as low as 68,000 (1957). In the same period, the entire Central Valley has ranged from 597,000 (1953) down to 117,000 (1957).

The spring run of the San Joaquin was 56,000 in 1945 but has been at or near zero since 1948. A complete estimate of the Sacramento spring run was first made in 1946 and last made in 1956. During that period it has varied from 26,000 (1946) down to 5,000 (1951).

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REPORT ON A CO-OPERATIVE, PRESEASON SURVEY OF THE FISHING GROUNDS FOR ALBACORE (*THUNNUS GERMO*) IN THE EASTERN NORTH PACIFIC, 1959[1]

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INTRODUCTION

Since about 1942, the northeastern Pacific albacore fishery has been worth an average of $6,000,000 annually to California fishermen alone. This, plus its value to the remainder of the Pacific coast fishing industry, places albacore among our most important fishery resources. Albacore landings are generally surpassed in weight by several other fishes, but in dollar value they consistently maintain a position among the top three commercial species. This high value is attributed to two factors: harvest of the domestic supply is limited by the seasonal nature of the fishery, and demand is high because superior packing qualities make albacore the only species that may be labeled "whitemeat tuna." Albacore are not only important for the livelihood of commercial fishermen, but as a highly prized gamefish, they provide recreation for thousands of sportfishermen principally along the California coast.

Albacore range throughout the north Pacific Ocean and are fished principally by Americans (east) and Japanese (middle and west). The relationship of the fisheries in the eastern, middle and western Pacific was cloaked in mystery for many years, but recent tag returns have indicated they may well be supported by a single population (Clemens, ms). Tagging also has demonstrated the same seasonal movements that catch records had indicated for many years (Clemens, 1955). Briefly, these movements may be summarized as: northward at least along the California coast during the summer and fall and westward across the Pacific toward Japan during the winter.

Little is known of the migration route into the eastern Pacific fishery except that it takes place sometime during spring. The location of early season concentrations of fish varies considerably, and annually presents a challenge to the fisherman as to where he should commence fishing. At times, fishermen have found it necessary to scout thousands of square miles of the sea along 300 miles or more of coastline. For several seasons prior to 1957 the first catches were located well to the south of Guadalupe Island, Mexico. Since that time the early concentrations occurred at varying distances to the north of the island.

[1] Submitted for publication June, 1960.

In order to learn more about the route of the spring migration and to assist the industry in opening the season earlier, the California Department of Fish and Game for several years has fielded an exploratory survey of the offshore fishing grounds prior to the regular season. A cruise such as this was planned for the month of June 1959. The Honolulu Biological Laboratory, U.S. Bureau of Commercial Fisheries, was contemplating a similar survey of the west coast fishing grounds during the same period. Since the desired results were identical, final plans were made for a co-operative survey. Participation of two vessels promised far greater coverage of the area and collection of an increased amount of oceanographic data that might be useful in predicting future occurrences of albacore.

This report describes the fishing methods and resulting catch related to sea surface temperature for the cruises of both agencies. Another report will summarize the combined oceanographic observations (Graham and Craig, ms).

VESSELS AND INTINERARY

Assigned to the survey were the *N. B. Scofield* (Cruise 59S4) from the California Department of Fish and Game and the *Hugh M. Smith* (Cruise 52) from the Honolulu Biological Laboratory. The two vessels explored the offshore waters along 600 miles of the North American coastline from the latitude of Point San Eugenia, Baja California to the latitude of San Francisco.

The offshore waters of central and southern California were chosen for the *N. B. Scofield* survey from June 1 through June 25, 1959. The actual survey consisted of a series of lines running roughly northwest and southeast between the Mexican boundary and San Francisco and offshore as far as long. 128° W. (Figure 1).

The *Hugh M. Smith* survey was conducted south of the *N. B. Scofield*, primarily off the coast of northern Baja California, Mexico, and east of long. 125° W. The vessel sailed from Honolulu on April 28, 1959, first occupying a series of preliminary fishing and oceanographic stations between Honolulu and the mainland. The cruise terminated in San Diego on June 19, 1959 (Figure 1). An unscheduled interruption in the early portion of the survey was necessitated by the illness of a crew member who was taken to San Francisco for treatment.

FISHING GEAR AND METHODS

Trolling lines, longlines and gill nets were used in attempting to locate albacore schools. Live anchovies were carried for hook and line fishing, but actually were used only occasionally to chum the jig lines. Both vessels were equipped with similar fishing gear except that the *N. B. Scofield* carried no longlines.

The Honolulu Biological Laboratory cruise plan emphasized occupying a series of predetermined longline and gill net stations, with trolling between these stations. The Department of Fish and Game plan emphasized trolling, with the use of gill nets secondary.

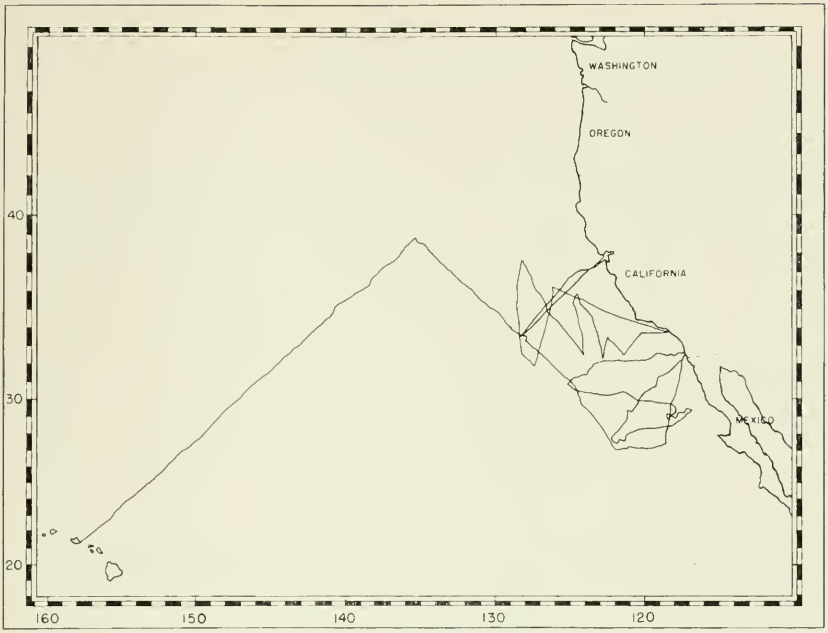

FIGURE 1. A portion of the eastern north Pacific Ocean illustrating schematically vessel tracks for the *N. B. Scofield* (Cruise 59S4) and *Hugh M. Smith* (Cruise 52) albacore survey, 1959.

Trolling Gear

The trolling gear was basically the same as that used by the commercial fleet (Scofield, 1956). Feathered japheads and bone jigs outfitted with barbless hooks were used on lines of varying length. Seven lines were trolled from the *N. B. Scofield*. These were arranged with a 20- and 15-fathom line on each outrigger pole and 7-, 9-, and 11-fathom lines fishing from the stern. The *Hugh M. Smith* trolled eight lines, two from each outrigger pole and four from the stern. Line lengths were alternately 15 and 30 fathoms (Figure 2).

Trolling was done during daylight at speeds ranging from 4 to 10 knots, but averaging six to seven.

Gill Nets

Both vessels were equipped with 10 shackles of nylon mesh gill net constructed by the Honolulu Biological Laboratory (Graham and Mann, 1959). Each shackle, 50 fathoms long by 4 deep, consisted of mesh sizes varying from $4\frac{1}{2}$ to $7\frac{1}{2}$ inches stretched measure. When setting from the vessel, shackles were arranged as follows: $4\frac{1}{2}''(1)$, $7\frac{1}{2}''(2)$, $6\frac{1}{2}''(4)$, $7\frac{1}{2}''(2)$ and $5\frac{1}{2}''(1)$.

Gill nets were set at dusk, the process requiring 30 to 60 minutes. Hauling took place at dawn the following day and required about one hour. The nets were set from the stern and hauled from the bow of the *N. B. Scofield*, and were both set and hauled from the bow of the *Hugh M. Smith*.

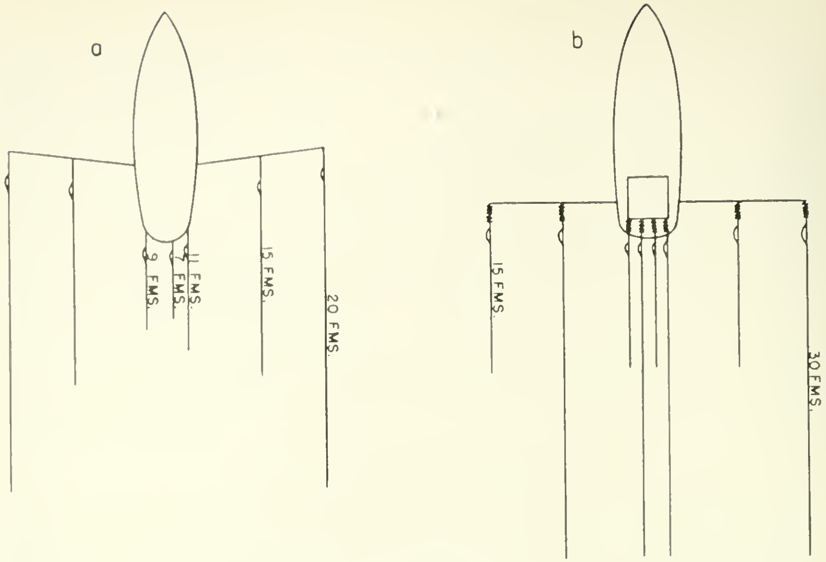

FIGURE 2. Arrangement and length of trolling lines on the *N. B. Scofield* (a) and *Hugh M. Smith* (b) albacore survey, 1959.

Longlines

Longlines used by the *Hugh M. Smith* were a modification of the gear originally developed at the Honolulu Biological Laboratory (Mann. 1955). Twenty baskets (210 fathoms per basket) of gear were fished at each longline station. The 12 droppers of a single basket were of varied length and in a set were arranged in three identical series as follows: 8, 2, 16, and 4 fathoms (Figure 3). Each dropper was buoyed separately to allow for a reasonably accurate estimate of the depth of capture.

Longlines were fished during daylight, usually from 0800 to 1400 hours. The gear required about 30 to 40 minutes to set and from 60 to 90 minutes to haul.

RESULTS OF FISHING

Trolling Catch

Of the three types of gear, trolling produced the only albacore catches. In all, 314 albacore were caught on trolling gear and of these, 207 were tagged and released (Table 1).

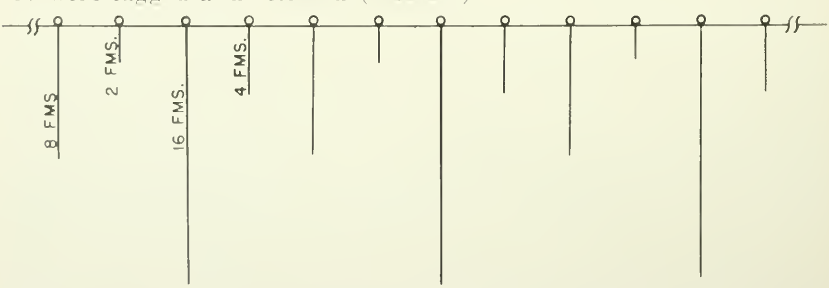

FIGURE 3. Arrangement of the droppers in a single basket (210 fathoms) of longline gear used on the *Hugh M. Smith* albacore survey, 1959.

TABLE 1

Troll Catches for the N. B. SCOFIELD (Cruise 59S4) and HUGH M. SMITH (Cruise 52), Albacore Survey, 1959

Date of catch	Position		Species	Number caught	Number tagged	Surface temperature degrees F.
	N. lat.	W. long.				
N. B. SCOFIELD						
6/ 5/59	34°46′	122°25′	Albacore	1	0	59.0
	34°47′	122°28′	Albacore	10	6	59.0
	34°49′	122°33′	Albacore	2	1	59.0
	34°52′	122°38′	Albacore	3	2	59.0
	34°56′	122°49′	Albacore	10	9	59.4
	34°59′	122°54′	Albacore	11	6	59.0
	35°01′	122°57′	Albacore	3	1	59.0
6/ 6/59	35°42′	124°45′	Albacore	1	1	59.4
6/ 7/59	35°50′	125°59′	Albacore	2	1	60.1
	34°50′	126°06′	Albacore	8	5	61.0
6/ 8/59	34°39′	126°16′	Albacore	5	5	61.0
	34°20′	126°22′	Albacore	1	0	60.3
	34°15′	126°23′	Albacore	7	3	60.6
	34°10′	126°26′	Albacore	2	1	60.6
6/12/59	36°31′	128°23′	Albacore	1	0	60.8
	36°39′	128°22′	Albacore	3	3	60.8
	36°45′	128°19′	Albacore	1	0	60.8
6/13/59	37°07′	128°18′	Albacore	1	0	61.0
	37°30′	128°06′	Albacore	3	2	61.0
	36°56′	127°38′	Albacore	2	1	60.4
6/15/59	35°24′	126°32′	Albacore	1	0	60.8
	34°48′	126°04′	Albacore	2	1	61.2
	34°34′	125°51′	Albacore	13	8	61.3
	34°25′	125°43′	Albacore	3	1	61.5
6/16/59	33°54′	125°12′	Albacore	1	1	60.4
	33°40′	125°00′	Albacore	37	22	61.2
	33°38′	124°58′	Albacore	4	3	60.6
	33°17′	124°40′	Albacore	5	3	60.6
6/17/59	32°34′	123°58′	Albacore	1	1	61.7
6/18/59	33°08′	124°06′	Albacore	2	2	59.5
	33°11′	124°07′	Albacore	3	3	59.5
	33°13′	124°09′	Albacore	5	3	59.5
	33°18′	124°09′	Albacore	7	5	59.4
	33°19′	124°09′	Albacore	8	7	59.5
	33°21′	124°10′	Albacore	6	3	59.5
	33°26′	124°11′	Albacore	2	1	59.7
	33°31′	124°14′	Albacore	3	1	59.7
	33°33′	124°14′	Albacore	2	0	59.7
	33°35′	124°15′	Albacore	1	1	59.7
	33°38′	124°15′	Albacore	5	3	60.3
	33°39′	124°17′	Albacore	6	3	60.3
	33°46′	124°18′	Albacore	24	18	60.4
	33°51′	124°20′	Albacore	3	1	60.3
6/19/59	33°37′	124°30′	Albacore	1	1	60.4
	33°49′	124°28′	Albacore	5	2	60.4
	34°02′	124°24′	Albacore	3	2	60.1
	34°28′	124°29′	Albacore	2	2	60.8
6/19/59	34°43′	124°33′	Albacore	5	4	60.3
6/20/59	34°47′	124°34′	Albacore	1	1	60.4
	34°53′	124°36′	Albacore	1	1	59.7

TABLE 1—Continued

Troll Catches for the N. B. SCOFIELD (Cruise 59S4) and HUGH M. SMITH (Cruise 52), Albacore Survey, 1959

Date of catch	Position N. lat.	Position W. long.	Species	Number caught	Number tagged	Surface temperature degrees F.
	34°57′	124°37′	Albacore	4	3	61.0
	35°00′	124°38′	Albacore	4	4	60.8
	35°02′	124°38′	Albacore	1	1	60.8
6/21/59	35°20′	123°51′	Albacore	1	0	60.1
6/22/59	33°38′	123°04′	Albacore	1	1	59.9
	33°32′	123°02′	Albacore	1	1	60.6
	33°29′	123°01′	Albacore	10	6	60.4
	33°25′	123°00′	Albacore	8	5	59.9
	33°23′	122°59′	Albacore	3	1	58.6
	33°17′	122°57′	Albacore	2	2	58.8
6/23/59	32°20′	122°44′	Albacore	5	3	61.3
	32°25′	122°43′	Albacore	6	5	61.3
	32°26′	122°40′	Albacore	4	4	61.3
	33°05′	122°32′	Albacore	2	0	61.2
	33°12′	122°31′	Albacore	2	1	60.8
	33°15′	122°30′	Albacore	4	4	60.6
	33°25′	122°28′	Albacore	3	2	61.0
6/24/59	32°45′	121°30′	Albacore	2	2	61.0
	32°41′	121°28′	Albacore	2	2	61.2
	32°37′	121°26′	Albacore	5	5	61.2
	32°33′	121°22′	Albacore	3	2	61.0
H. M. SMITH						
4/29/59	23°29′	155°07′	Dolphin	1	0	73.0
5/3/59	33°09′	143°00′	Skipjack	2	2	63.9
5/9/59	36°44′	132°26′	Albacore	2	2	60.8
6/13/59	27°26′	121°49′	Skipjack	1	0	64.8

The *Hugh M. Smith* traveled approximately 6,000 miles during the 53 days of the cruise. This mileage was divided almost equally between the survey area, east of long. 125° W., and the preliminary route from Honolulu to this area. Lines were trolled for approximately 1,900 miles in the primary survey area and over 1,500 miles enroute, and 13 gill net and nine longline sets were made (Figure 4). Two albacore were caught on trolling lines and tagged some 500 miles west of San Francisco. Three skipjack *(Katsuwonus pelamis)* and a single dolphin *(Coryphaena hippurus)* were the only other fish caught on this gear.

The *N. B. Scofield* traveled approximately 2,400 miles during the 25-day cruise. Lines were trolled for about two-thirds of this distance and in addition a single gill net set was made (Figure 5). The first schools of albacore were encountered between 90 and 120 miles west by north of Point Arguello early in the cruise. Subsequently, 312 were caught of which 205 were tagged and released at numerous localities. Severe northwesterly weather conditions prevailing throughout the northern survey area hampered fishing in most areas. No other species of fish was caught by the *N. B. Scofield* on trolling lines.

Gill Net Catch

Of 13 gill net stations occupied by the *Hugh M. Smith*, all but three were in the primary survey area. The first set was made on May 4, and the last on June 18. All were made in water ranging from 57.5 to 65.8 degrees F. at the surface. No albacore were netted. Six other kinds of fish were caught, including: skipjack, Pacific bonito *(Sarda chiliensis)*, pomfrets, blue shark *(Prionace glauca)* and bonito shark *(Isurus glaucus)* (Table 2). A set was made on May 9, near where two albacore

TABLE 2
Gill Net Sets Made by the N. B. SCOFIELD (Cruise 59S4) and HUGH M. SMITH (Cruise 52), Albacore Survey, 1959

Date of set	Position		Species	Number caught	Surface temperature degrees F.
	N. lat.	W. long.			
N. B. SCOFIELD					
6/11/59	35°35′	128°28′	No catch		61.2
HUGH M. SMITH					
5/ 4/59	34°48′	140°41′	Bonito shark	1	62.1
			Pomfret	25	
5/ 7/59	38°48′	135°06′	Blue shark	4	57.5
			Pomfret	7	
5/ 9/59	36°39′	132°24′	Blue shark	1	61.2
			Pomfret	2	
5/22/59	26°59′	121°59′	Skipjack	6	65.0
5/23/59	27°00′	120°56′	No catch		65.8
5/24/59	27°00′	119°31′	No catch		65.5
5/30/59	32°30′	118°20′	Blue shark	4	62.1
			Bonito shark	1	
5/31/59	32°08′	119°35′	Blue shark	3	60.0
6/ 4/59	30°28′	123°35′	No catch		62.2
6/ 9/59	28°50′	117°57′	Dolphin	1	64.5
6/10/59	29°23′	117°00′	Bonito shark	1	63.5
6/13/59	27°33′	122°15′	Pomfret	1	64.8
6/18/59	31°59′	117°46′	Pacific bonito	4	65.4
			Blue shark	4	
			Bonito shark	1	

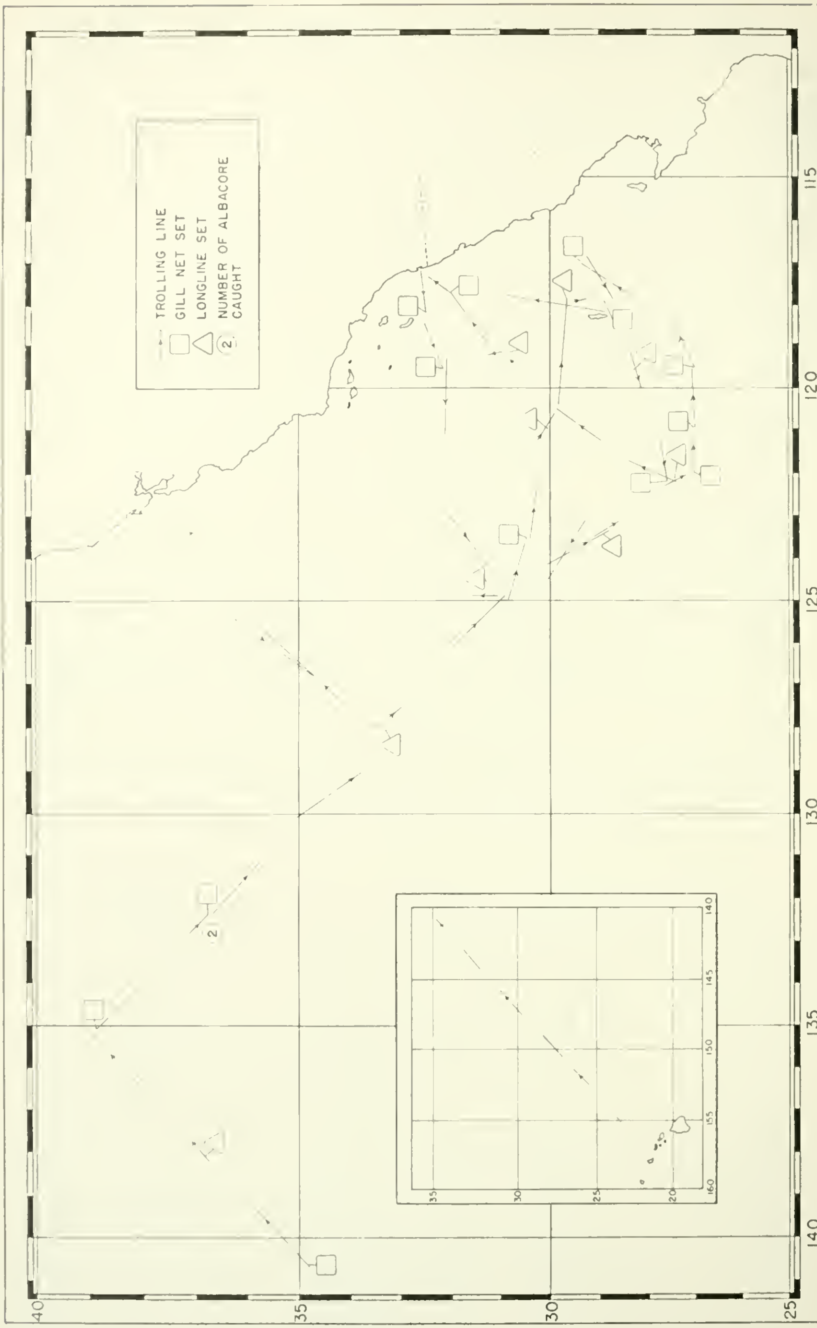

FIGURE 4. Actual trolling lines of the *Hugh M. Smith* showing relative position of gill net and longline sets and the location of albacore catches. Inset shows trolling lines between Honolulu and long. 140° W.

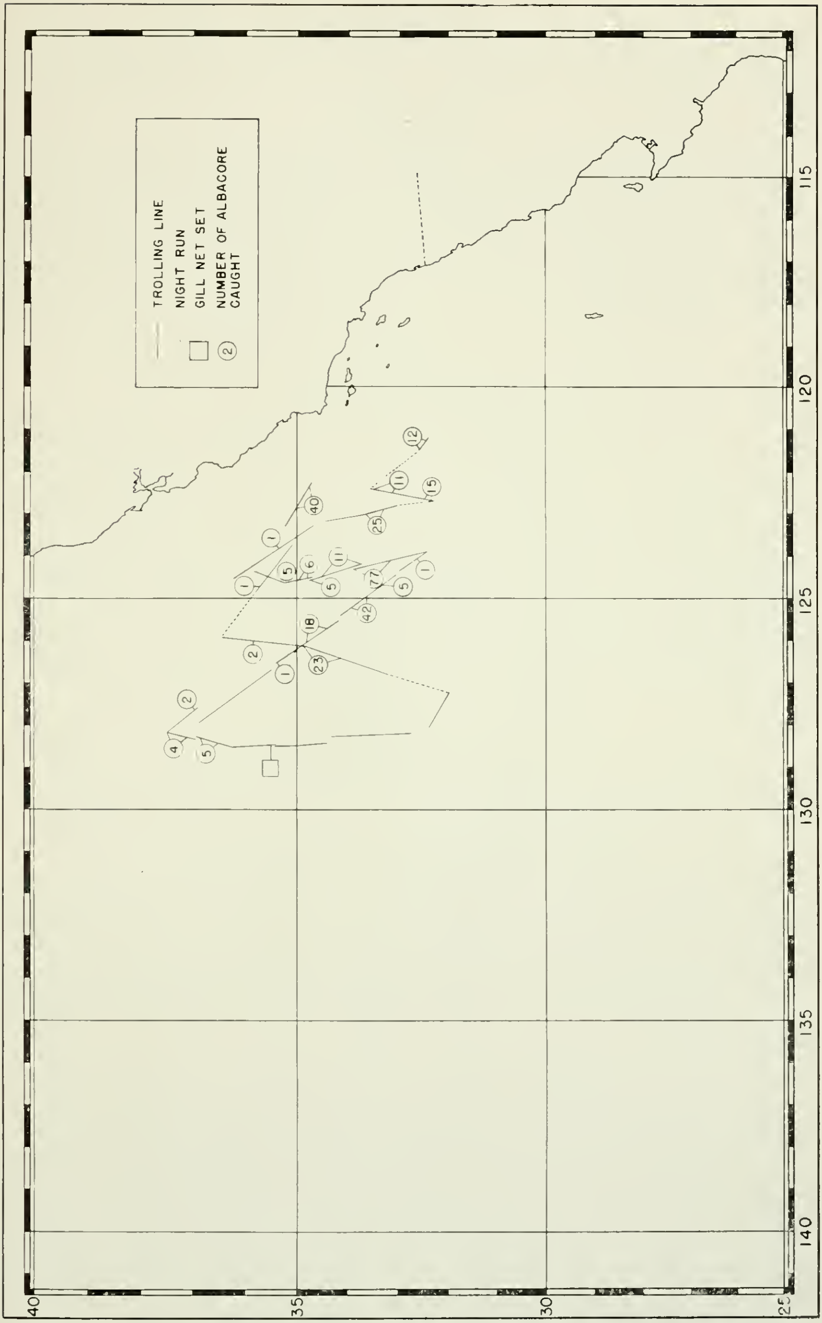

FIGURE 5. Actual trolling lines of the *N. B. Scofield* showing location of albacore catches and the relative position of the single gill net set.

had been caught on trolling lines, but only blue sharks and pomfrets were caught.

A single gill net set from the *N. B. Scofield*, approximately 390 miles west by north of Point Arguello on June 11, in 61.2-degree F. water, caught no fish.

Longline Catch

The first of nine longline stations occupied by the *Hugh M. Smith* was on May 6, and the last on June 17. All but two were in the primary survey area. Surface temperatures at the longline stations ranged from 60.9 to 64.7 degrees F. No albacore were caught, but three other kinds of fish including: bigeye tuna *(Parathunnus sibi)*, hammerhead sharks (*Sphyrna* sp.) and blue sharks were taken (Table 3). The *N. B. Scofield* did not use this gear.

TABLE 3
Longline Sets Made by the HUGH M. SMITH (Cruise 52), Albacore Survey, 1959

Date of set	Position N. lat.	Position W. long.	Species	Number caught	Surface temperature degrees F.
5/6/59	36°48′	138°05′	Blue shark	4	61.3
5/17/59	33°19′	128°01′	Blue shark	2	60.9
5/21/59	28°56′	123°27′	No catch		63.8
5/22/59	27°23′	122°09′	No catch		64.7
6/3/59	31°07′	124°56′	Blue shark	1	61.7
6/6/59	30°03′	120°58′	Blue shark	3	61.9
6/8/59	29°38′	117°55′	Bigeye tuna	2	63.6
			Blue shark	6	
			Hammerhead shark	1	
6/12/59	28°15′	119°34′	Blue shark	1	64.1
6/17/59	30°47′	119°10′	Blue shark	4	62.5
			Hammerhead shark	1	

SIZE RANGE OF THE ALBACORE CATCH

Based upon a frequency distribution of 199 albacore tagged by the *N. B. Scofield* (Table 4), over 80 percent of the catch was within the size range 630 to 680 mm. fork length (approximately 11 to 14 pounds). Lengths of untagged fish were similar and none was outside of the above size range. Weights recorded for the two albacore tagged from the *Hugh M. Smith* were 8 and 12 pounds, well within the overall size distribution.

SEA SURFACE TEMPERATURES AND ALBACORE OCCURRENCES

Rather comprehensive records of sea surface temperature were maintained aboard both vessels. In general, surface temperatures within 50 miles of shore varied from 54 degrees F. around Santa Rosa and San Miguel Islands to over 70 degrees F. along the immediate southern California coast and within a few hundred miles of the Hawaiian Islands. Offshore in the actual survey areas the range was between 57 and 65 degrees F.

Surface temperature records were sufficiently detailed to make it possible to construct rough isotherms within the survey area. Plotting

TABLE 4

Lengths of 199 Albacore Tagged from the N. B. SCOFIELD, Albacore Survey, 1959

Length (cm.)	Frequency	Percent	Length (cm.)	Frequency	Percent
56	1	0.5	67	25	12.6
57	0	--	68	15	7.5
58	1	0.5	69	8	4.0
59	2	1.0	70	0	--
60	1	0.5	71	0	--
61	2	1.0	72	1	0.5
62	7	3.5	73	1	0.5
63	15	7.6	74	1	0.5
64	36	18.1	75	0	--
65	48	24.1	--	--	--
66	34	17.1	81	1	0.5

albacore occurrences on a chart of these isotherms shows the relationship of the catches to surface temperature (Figure 6).

Ninety-eight percent of the albacore caught were from the rather restricted temperature range of 59.0 to 61.3 degrees F. (15.0 to 16.3 degrees C.). The remaining two percent were caught within plus or minus 0.4 degrees F. from these extremes (Table 5). Though surface temperatures where albacore occurred during May and June 1959 tended toward the lower extreme, they were predominantly within the range of 60 to 69 degrees F. from which California fishermen reported over 90 percent of their catch during the period 1955 through 1957.

TABLE 5

Albacore Troll Catches by Temperature, Albacore Survey, 1959

Temperature		Catch		Temperature		Catch	
Degrees C.	Degrees F.	Number	Percent	Degrees C.	Degrees F.	Number	Percent
14.8	58.6	3	0.96	15.8	60.4	44	14.01
14.9	58.8	2	0.64	15.9	60.6	23	7.32
15.0	59.0	30	9.55	16.0	60.8	17	5.41
15.1	59.2	0	0.00	16.1	61.0	29	9.23
15.2	59.4	18	5.73	16.2	61.2	48	15.29
15.3	59.5	24	7.64	16.3	61.3	28	8.92
15.4	59.7	9	2.87	16.4	61.5	3	0.96
15.5	59.9	9	2.87	16.5	61.7	1	0.32
15.6	60.1	6	1.91				
15.7	60.3	20	6.37	Total		314	100.00

SUMMARY

1. In an attempt to obtain an early opening for the 1959 season and to learn the route of the spring migration of albacore a joint, preseason survey of the fishing grounds was carried out by the California Department of Fish and Game and the Honolulu Biological Laboratory, U.S. Bureau of Commercial Fisheries.

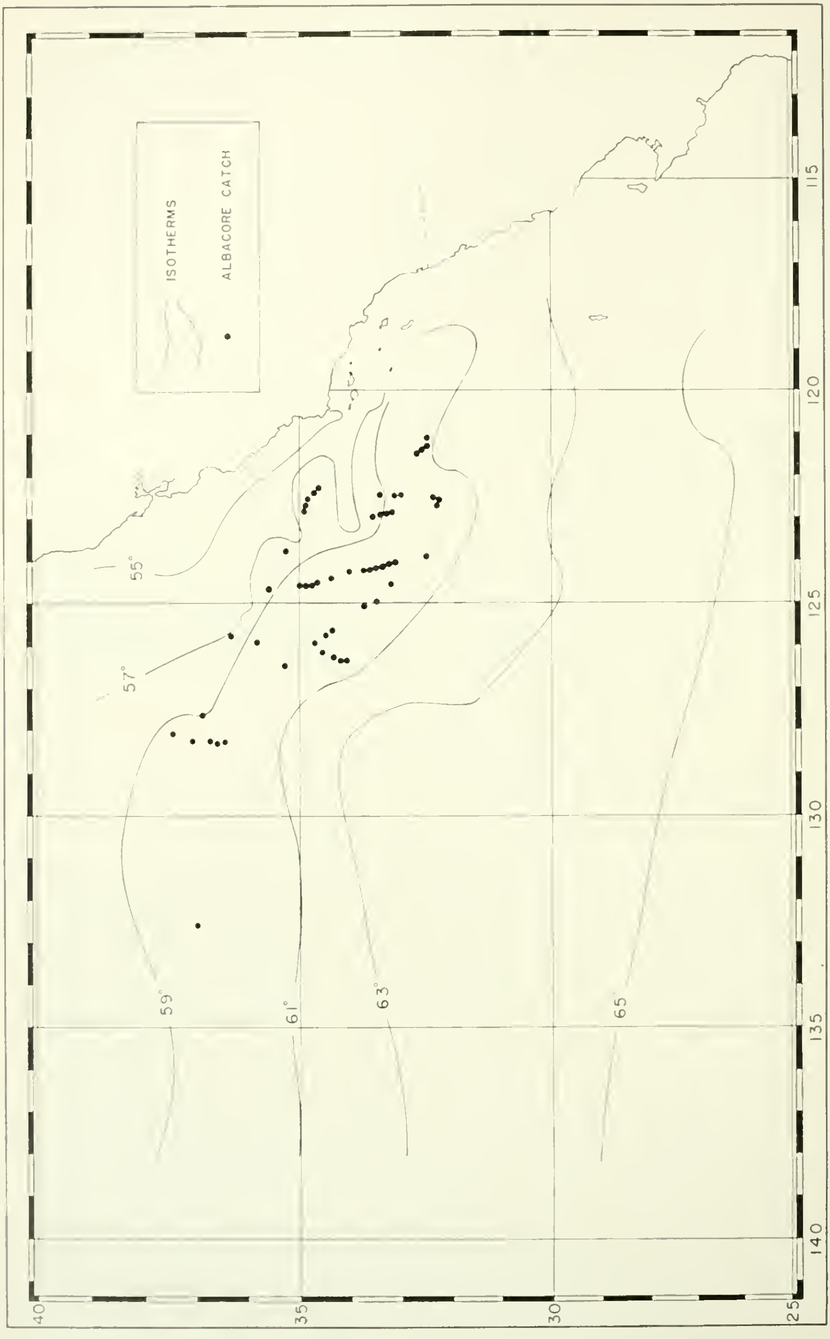

FIGURE 6. Albacore catch locations related to surface isotherms, by two degree F. intervals, as interpreted from sea surface temperature data collected during the 1959 survey.

2. The California Department of Fish and Game vessel *N. B. Scofield* surveyed the offshore fishing grounds north of Lat. 32° N. from June 1 through June 25, 1959. The Bureau of Commercial Fisheries vessel *Hugh M. Smith* surveyed to the south of Lat. 32° N. from April 28 through June 19, 1959.
3. Fishing gear consisted of feather and bone jigs, longlines and gill nets.
4. Trolling north of Lat. 32° N. produced the only catches of albacore. Of 314 caught trolling, 207 were tagged and released.
5. Fourteen gill net sets and nine longline sets caught no albacore. These two types of gear did produce small catches of bigeye tuna, skipjack, Pacific bonito, pomfrets, dolphin, blue shark, bonito shark and hammerhead shark.
6. The predominant size group of albacore caught was from approximately 11 to 14 pounds.
7. Offshore sea surface temperatures ranged from about 57 to 65 degrees F. Albacore occurrences were limited to a range between 58.6 and 61.7 degrees F.

ACKNOWLEDGMENTS

The authors wish to extend their gratitude to the captains and crews on the *N. B. Scofield* and the *Hugh M. Smith*. Without their splendid support, often under trying conditions, the data presented in this paper could not have been obtained.

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CONSTRUCTION AND OPERATION OF A SMALL BOAT TRAWLING APPARATUS[1]

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The constant need for improved collecting devices stimulates experimentation for new and more efficient methods. Much of the research of the fishery biologist depends upon the development of specialized equipment.

An inexpensive and completely portable trawling apparatus developed at U.C.L.A. has substantially improved our trawling success for shallow water fishes. It is designed to be used in small boats powered by an outboard motor, and can be efficiently operated by two people in waters deeper than 150 feet.

Commercial trawlers are a rich source of specimen material for the collector but they have a number of disadvantages. They fish with large mesh sizes, in restricted localities, in certain seasons, and are not always available. Quite often many good collecting areas are missed because of these reasons. Minimum mesh size is an excellent conservation measure but allows many of the smaller and equally important specimens to pass through the net. Because of their size, commercial trawlers are compelled to operate several miles out from shore, thereby leaving an important inshore zone unavailable for collecting specimens by this means.

Many rare and important specimens in the U.C.L.A. fish collection were obtained by collecting in the shallow inshore zone with the portable trawling apparatus. It permits the fishery worker to operate freely in these shallow areas normally out of reach of the commercial trawler.

DESIGN AND EQUIPMENT

A portable trawling winch and component equipment similar to ours can be made to fit many designs of small boats that use an outboard motor. Boats having moderately flat bottoms, wide beams, and high freeboards are recommended. It may be necessary to install additional supports to the transom and seats due to the weight and stresses subjected to the boat by the trawling equipment. We have found that a standard 15½-foot fiberglass outboard hull worked efficiently with the addition of two quarter knees to the transom and greater support to the seats.

Boats smaller than this are not recommended since it is doubtful that they could be used safely with this equipment. The weight of two operators, all the trawling equipment, the outboard motor and two fuel tanks is in the neighborhood of 700 pounds. These plus the down-

[1] Submitted for publication, April, 1960.

ward force of the trawl cable on the stern subject the hull to a weight load that can be safely handled only by a larger boat. At least a six-foot beam and a 15-inch freeboard at the stern are recommended. Most outboard hulls are constructed to accommodate a standard-shank outboard motor with usually a maximum of 15 inches of freeboard at the stern. It would be advisable to use a longer shank outboard motor, thereby allowing construction of a higher transom with added freeboard. By using a long-shank motor a transom height of 20 inches or more may be reached.

It is important when working in salt water to use noncorrosive materials wherever possible in the construction of the boat, trawling winch, and component equipment.

The size and style of outboard motor is optional depending on individual desires. We have had excellent results using a popular brand 25-horsepower outboard motor equipped with a standard pitch propeller. Outboard motors of less than 25-horsepower are not recommended because of the high rate of engine speed needed with the smaller sized motors.

It is advisable to carry at least two six-gallon fuel tanks in the boat to allow from four to six hours of uninterrupted trawling.

The winch consists of a cable drum driven by a Briggs and Stratton gasoline engine through a gear reduction box. The cable drum is controlled by a friction clutch and a contracting brake operated by two conveniently placed hand levers. A hand throttle mounted to the trawl winch frame controls the engine and cable drum speed allowing the cable to be spooled in at a rate of 40 to 120 feet per minute. Accidental unwinding of the trawl cable is prevented by a stop rachet pawl acting on the sprocket of the cable drum. As an added convenience, a "gypsy head" is mounted on the end of the drum drive shaft opposite the speed reducer. The complete trawl winch assembly is mounted in a light angle-iron frame that secures to the front boat seat by four brass bolts.

For ease in handling, the trawl winch assembly should be as light as possible without sacrificing any detail contributing to its performance. The complete trawl winch assembly with trawling cable weighs approximately 180 pounds. Overall weight may be reduced by using a smaller diameter trawl cable and by excluding the "gypsy head."

The various units of the trawl winch assembly and their approximate weights are:

Briggs and Stratton Engine	25 pounds
Ohio Speed Reducer	35 pounds
Trawl Cable Drum	15 pounds
600 feet of $\frac{3}{16}$-inch steel cable	45 pounds
"Gypsy Head"	15 pounds
Trawl Frame Assembly	45 pounds

Because of the strong backward pull of the trawl cable on the winch it is necessary to attach a stress cable to prevent the forward seat from being pulled out. This is easily done by making a Y-shaped cable bridle with a turnbuckle fastened to one end and a brass spring snap fastened to each of the other two ends. The brass spring snaps attach to a stationary ring at each gunwale near the bow. The turnbuckle hooks onto the winch frame and is tightened slightly so that any backward

movement of the trawl winch will be stopped by the stress bridle thus preventing damage to the forward boat seat.

The $\frac{3}{16}$-inch steel cable spooled onto the cable drum passes back and over the stern with a net bridle spliced on the end for attaching the two otter boards. The operating depth of the trawl winch may be extended by equipping the cable drum with a smaller diameter cable. The principal reason for using a $\frac{3}{16}$-inch cable was for ease in handling in case of equipment failure requiring manual pulling. A pipe frame fitting into four brass sleeves mounted on the inside of the transom supports a pulley assembly on which the trawl cable rides at all times during operations. The pipe transom frame also provides a convenient place for hanging the otter boards when the net is brought up. As a convenience in handling specimens, a removable sorting table is mounted onto the gunwale between the two boat seats.

A removable canvas awning supported by four pipe uprights can be easily added to protect equipment and personnel from the elements. Some type of protection from the sun and weather is quite important when operating in tropical localities where extremes in temperature and humidity are common.

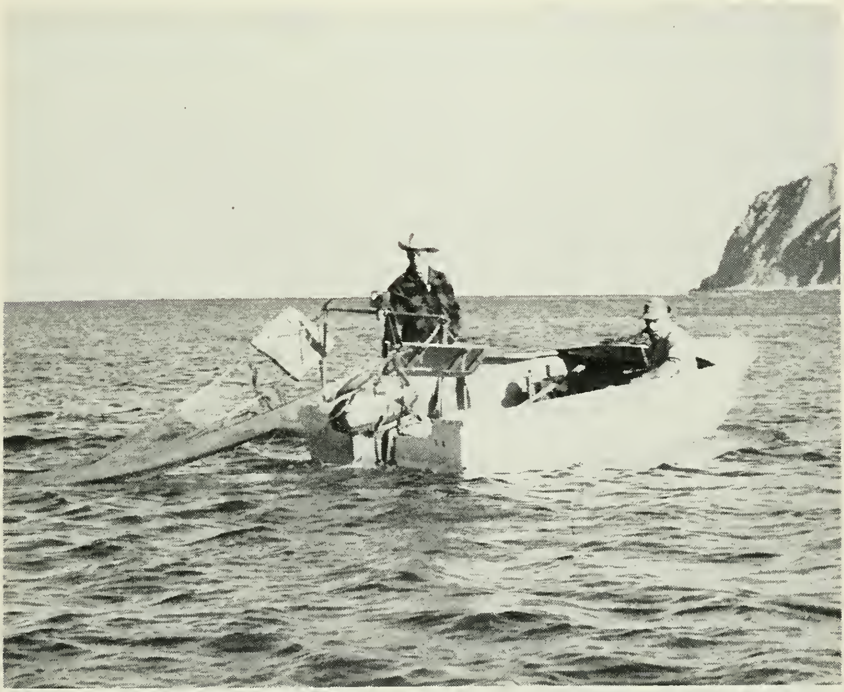

FIGURE 1. The small boat trawling apparatus in operation showing the net and otter boards in position to be set. *Photograph by the author, January 1959.*

This trawling apparatus can be used for many purposes with little or no change in design. It can be used for towing plankton nets, dredges, small beam trawls, and with the addition of a "gypsy head" for raising and lowering various types of fish traps. Transporting the

boat and equipment is no problem since the boat can be carried on a standard boat trailer and the trawling apparatus loaded into the towing vehicle along with the other collecting equipment.

OPERATION OF EQUIPMENT

Two persons can operate the equipment; one operating the outboard motor, the other operating the trawl winch. The net is laid out over the gunwale and both otter boards hung on the transom frame. Prior to setting the net, it is advisable to take a sounding to determine how much cable should be spooled out. It is not necessary to start the trawl winch motor when setting the net but the stop ratchet pawl on the cable drum should be disengaged. With five or six feet of slack in the trawl cable and the clutch on the trawl winch in neutral, the boat is run forward at a moderate speed, the net is thrown over the side and the otter boards unhooked and dropped off the stern. By operating the brake lever a slight tension can be kept on the cable to prevent the otter boards from collapsing. When sufficient cable is let out, the cable drum is stopped with the brake lever and the ratchet pawl dropped into place.

Several sample hauls of 10 to 15 minutes should be run to determine the most favorable length of time the net should be on the bottom. A long trawling time may result in loading the net excessively and trouble may be had in bringing it up especially in choppy seas. In most of the areas where we have worked no more than 10 or 15 minutes at a speed of two to three miles per hour were required to fill the net. During the 10 or 15 minutes of fishing time the specimens collected on the previous haul can be sorted and placed in containers leaving the sorting table clear for the following catch.

The trawl is brought in by starting the winch motor and engaging the clutch, the ratchet pawl need not be engaged until the net and otter boards are nearly in. The speed of the incoming trawl cable is governed by the amount of throttle given the winch motor. Until the net approaches the boat it can be spooled fairly rapidly—to about 120 feet per minute. At the time the trawl bridle breaks the surface the speed of the incoming cable should be reduced and the forward speed of the boat maintained to prevent the net from becoming entangled in the propeller. When the otter boards reach the stern, the winch motor is shut off and both boards hung onto the transom frame. By increasing the speed of the boat the net is pulled to the surface and stretched out behind and into position to be brought alongside. The outboard motor is then turned hard left making the net stretch out from the stern toward the right side of the boat. By shifting the outboard motor into reverse and gradually backing, the cod end of the net is swung below the right gunwale in position to be lifted aboard. The motor is then stopped, the cod end of the net lifted aboard and emptied on the specimen sorting table on the opposite side of the boat.

After emptying the specimens and reclosing the cod end, the net is placed on the right gunwale in position to be reset. Usually after only several hauls one can operate in the procedure described above with efficiency and speed.

DESCRIPTION OF COMPONENTS

Portable Trawling Winch

The winch is a cable-drum-type with a capacity of approximately 600 feet of $\frac{3}{16}$-inch stainless steel aircraft cable (Figure 2). It has a drum with a 10-inch flange diameter, 4-inch spool length, $2\frac{1}{2}$-inch spool throat diameter. One side of the drum is equipped with a cone friction clutch and a contracting band-type brake. Both clutch and brake are operated by hand levers. The opposite side of the cable drum is equipped with a positive stop ratchet pawl acting on the drum sprocket to prevent accidental unwinding of the cable. A $5\frac{1}{2}$-inch diameter "gypsy head" is mounted on one end of the drum driveshaft which rotates continuously when the engine is running and is independent of the cable drum.

A 50:1 ratio Ohio speed reducer unit is connected to the clutch side of the drum driveshaft by a coupling. It develops a torque of 600-inch-pounds at .625 input horsepower at 1,800 rpm. The speed reducer will allow a cable speed of 40 to 120 feet per minute depending on the speed given the engine.

A Briggs and Stratton gasoline engine, model 8B with a horsepower rating of 2.75 at 3,600 rpm drives the unit through a 1:1 ratio "V" belt drive from the engine to the input shaft of the speed reducer. The

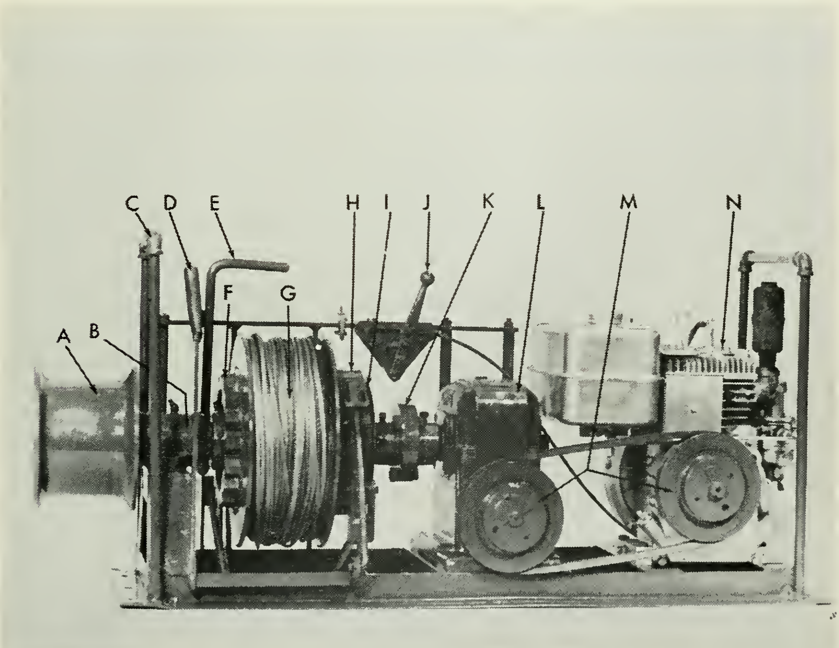

FIGURE 2. The portable trawl winch assembly is mounted on the forward boat seat with the cable drum approximately amidship. **A,** "gypsy head"; **B,** driveshaft bearing; **C,** carrying handle; **D,** brake lever; **E,** clutch lever; **F,** cable drum sprocket; **G,** cable drum with 600 feet of 3/16-inch cable; **H,** contracting brake band; **I,** cone friction clutch; **J,** throttle; **K,** driveshaft coupling; **L,** 50:1 ratio Ohio speed reducer; **M,** 1:1 ratio "V" belt drive; **N,** 2.75 horsepower Briggs and Stratton gasoline engine. *Photograph by the Author, March 1960.*

motor speed is controlled by a hand throttle attached to the trawl frame assembly.

The entire assembly is mounted on a light angle-iron frame with a carrying handle welded to each end. The overall dimensions of the completed apparatus are: length 40 inches, width 12½ inches, height 15½ inches.

When in operating position, the winch assembly is securely mounted to the forward boat seat by brass bolts which require only several minutes to install. It is advisable to have the trawling winch situated forward in the boat to help counteract the weight of the outboard motor and the downward force of the trawl cable.

Trawl Pulley and Transom Frame

The trawl pulley assembly which mounts over the outboard motor on a pipe frame (Figure 3) is a simple brass pulley wheel 4 inches in length, 3 inches in diameter, mounted in a stainless steel housing. A 1-inch shaft welded to the underside of the pulley housing fits into a vertical sleeve at the center of the transom frame and is held in position by a locking pin. The locking pin prevents the pulley housing from turning and insures against accidental loss overboard of the pulley assembly. A brass spring latch on top of the pulley housing which can open and close, prevents the trawling cable from slipping off the pulley wheel. Many variations in design are acceptable for a stationary pulley

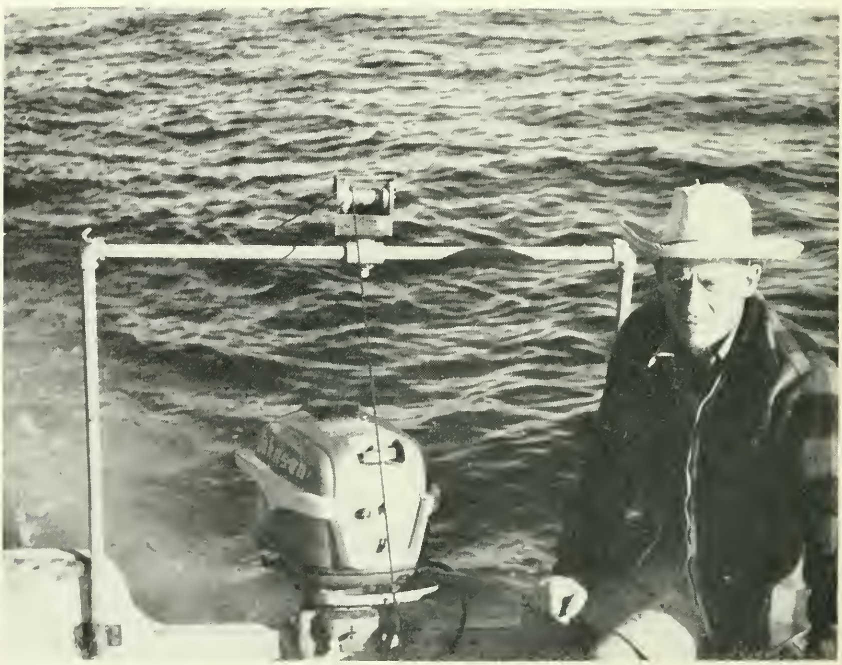

FIGURE 3. The pipe transom frame supports the pulley assembly on which the trawl cable rides during operations. The metal hooks at each corner are for hanging the otter boards. *Photograph by the author, January 1959.*

of this type but the pulley wheel itself should be wide enough to allow free passage of the trawl cable and bridle.

The transom frame (Figure 3) is made of $\frac{3}{4}$-inch galvanized pipe and is used to support the pulley assembly over the stern. Two upright legs, 45 inches in length are joined to a 44-inch crossmember on which a sleeve is welded at the center to receive the shaft of the pulley housing. The crossmember and uprights are joined by two 90-degree elbows and spot welded to prevent rotation. On top of each 90-degree elbow a short hook is attached for hanging the otter boards when not fishing. The lower section of the transom frame should be bent to coincide with the angle of the boat transom allowing the two uprights to maintain a vertical position.

Transom Sleeves

Four 3-inch brass sleeves are bolted to the inside of the transom in such a position as to receive the two legs of the transom frame. Each sleeve is constructed of $\frac{1}{8}$-inch brass stock with an inside diameter of $1\frac{1}{8}$ inches. A 2-by-4-inch brass plate is brazed to the sleeve and used to mount it to the boat transom by four $\frac{1}{4}$-inch brass bolts. Two of these sleeves (Figure 4) are mounted one over the other near each corner of the transom, each pair placed 45 inches apart to receive the pipe uprights of the transom frame. The lower sleeves have a brass stop brazed onto the underside to retain the frame uprights in position. It is these lower sleeves that receive all the downward force created by the trawl net onto the cable. Enough spacing should be allowed between the brass sleeves and the $\frac{3}{4}$-inch pipe uprights to prevent freezing due to encrusting salt and sand deposits.

Specimen Sorting Table

Made from one sheet of $\frac{1}{4}$-inch plywood, 36 by 36 inches, a sorting table was added for convenience in handling specimens (Figure 5). To all four edges, a $3\frac{1}{2}$-inch high side board was added with drain holes cut into the outboard edge. The table is set onto the left gunwale and held in place by three wooden blocks attached to the underside which fit the contour of the gunwale. The inboard end of the table is supported by two removable $\frac{1}{2}$-inch galvanized pipe legs that screw into pipe flanges bolted to the underside. After the catch is emptied from the net onto the sorting table it can be easily washed free of mud, sorted, and the specimens placed into containers. This not only prevents the boat and equipment from becoming covered with mud but helps keep the specimens in a clean condition for preservation. A sorting table of this nature is an important feature since a majority of the specimens are usually collected along with unwelcome mud and refuse. As an added convenience the surface of the table is painted a light gray and can be used as a background for photographing specimens.

Trawl Net and Equipment

Since this method of trawling is designed to operate with a single line, it is necessary to construct a net bridle at the end of the trawl cable for attaching the otter boards. Two lengths of $\frac{3}{16}$-inch stainless steel cable at least 25 feet in length can be simply spliced onto the end of the trawl cable. If desired, a small swivel may be added, but it

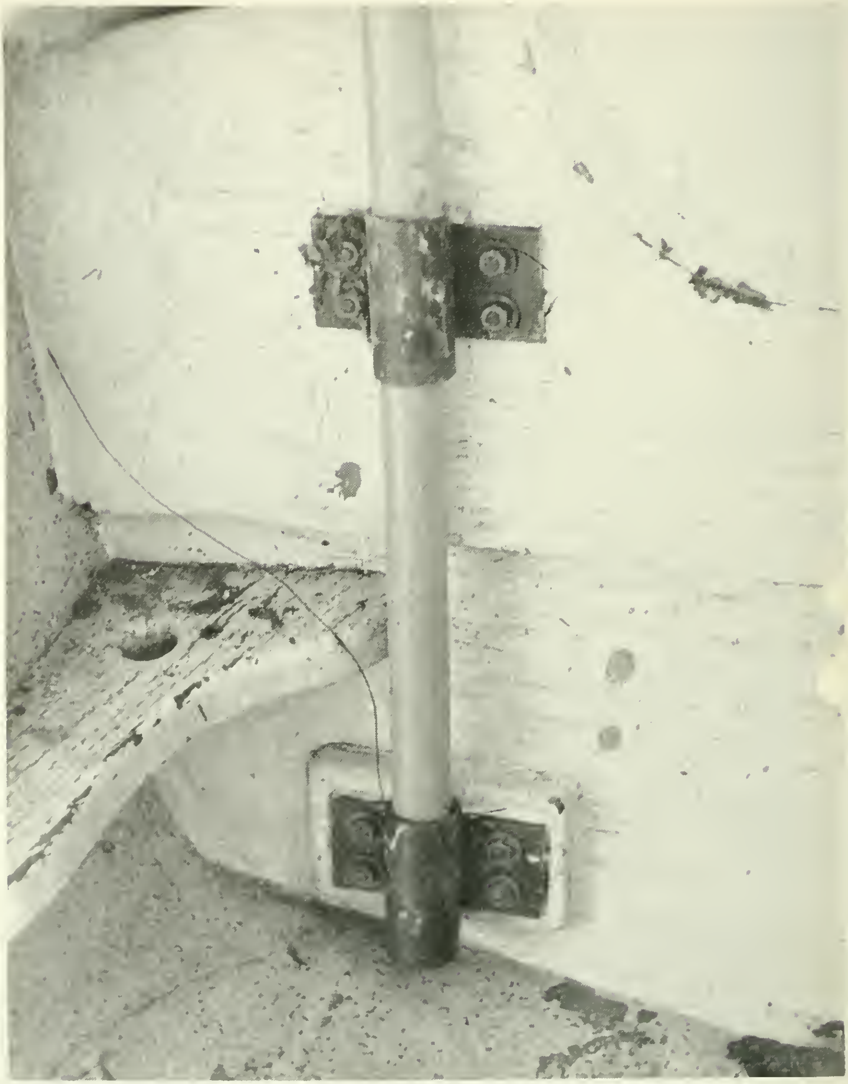

FIGURE 4. The tronsom sleeves receive the uprights of the pipe transom frame. The quarter knee at left was added far support to the tronsam. *Photograph by the authar, January 1959.*

should be small enough to freely pass over the trawl pulley and onto the cable drum. A wire rope thimble is spliced onto each end of the bridle cables allowing the otter boards to be attached with metal shackles.

Lightweight semiballoon trawls of several sizes were used with excellent results. The 16-foot size trawl with a ¼-inch mesh liner added to the cod end proved very productive and quite easy to handle. Sizes larger than this may be more difficult to work with due to the required increase in size and weight of the otter boards.

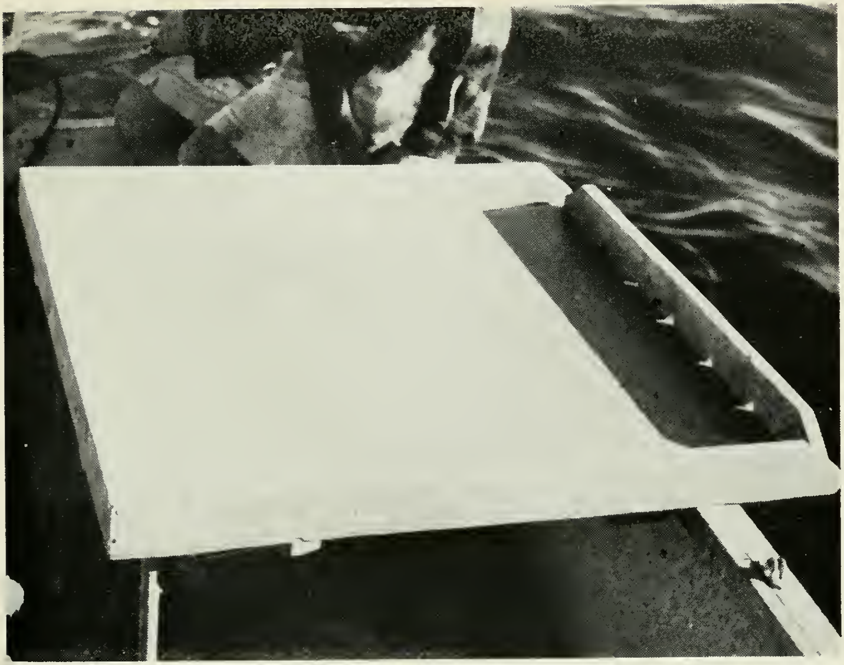

FIGURE 5. The specimen sorting table can be used on either gunwale. The catch is emptied onto this table, washed, sorted, and placed in containers stored underneath.
Photograph by the author, January 1959.

The otter boards are a standard design used by shrimp trawlers, with their exact size depending upon the size of net used. With the 16-foot trawl net, doors 25 inches long by 16½ inches wide were used with excellent results. Usually extra hardware and several extra trawl nets complete with ¼-inch mesh liners are carried in case of equipment failure or net damage that may require considerable time to repair with loss to fishing time.

ACKNOWLEDGMENTS

Acknowledgments are due to Mr. Dorwin E. White of Whitey Machine Works, San Pedro, California, who originally designed and constructed the portable trawling winch. I wish to thank Mr. Frank Brocato and Mr. Frank Calandrino for their advice during construction of the trawling winch and component equipment. Thanks are also due to Dr. B. W. Walker and Mr. J. E. Fitch for their helpful suggestions and for reading the manuscript.

THE FIRST RECORDED MASS STRANDING OF PELAGIC RED CRABS, *PLEURONCODES PLANIPES*, AT MONTEREY BAY, CALIFORNIA, SINCE 1859, WITH NOTES ON THEIR BIOLOGY[1]

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INTRODUCTION

During January 12 and 13, 1960, the telephone calls coming into the Hopkins Marine Station became more frequent than usual. Many of the ensuing conversations were quite different, too, often developing into an excited story about a strange, little, red lobster that had washed up on the Monterey beach by the thousands. For the contemporary populace of the Monterey Peninsula this was a completely new and interesting event to behold—and, indeed, for the more venturesome gourmet perhaps a novel *hors d'oeuvre*, or a red crab cocktail.

Advantage was immediately taken of this unique event and the stranded population was sampled in terms of sizes, sex ratio and percentage of gravid females. These are discussed in this paper as well as the apparent correlation between the northward appearance of this normally warmer water form with the recent warming of the sea off the California coast.

MASS STRANDING AND GENERAL OCCURRENCE IN BAY

The greatest concentration of the red crabs to reach the shore occurred on January 12, between the two piers on the sandy beach at the city of Monterey (Lat. 36° 36′ 06″ N., Long. 121° 53′ 24″ W.). During this time the tide was receding, making it possible for planktonic organisms to become stranded if too close to shore. A similar event took place the next day, during the receding tide, but down the beach 100 feet or so in a southerly direction. This second wave of red crabs to come ashore was not so extensive as that of the preceding day.

The first day, *P. planipes* formed a windrow-like band, two yards wide, stretching for at least 300 feet along the shoreline. Despite considerable gorging by shore birds and collecting by enthusiastic fishermen, an estimated 10,000 individuals were in this band. With a minimum estimate of 5,000 the second day, the grand total beached, before predation and collecting by the public, probably was close to 30 or 40 thousand.

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[1] Submitted for publication April 1960.

According to Stimpson, in W. L. Schmitt's monograph, *The Marine Decapod Crustacea of California*, the first reported mass stranding of *P. planipes* occurred in March on the Monterey Peninsula, 101 years earlier.

In addition to the occurrence of the red crab on the shore, great numbers were encountered at sea on January 27. These were sighted from the *Tage*, the research vessel of the Hopkins Marine Station, at and near the surface, along the coastline between the harbor of Monterey and Point Pinos. This shoal was located about 300 yards northeast of Point Pinos. As the *Tage* cruised along through this most concentrated stretch of crabs, approximately 200 individuals could be seen at any one time from the bow for at least a quarter of a mile. Thousands of gulls, cormorants and alcids were levying a heavy toll upon them. The surface sea temperature in the vicinity was 12.8 degrees C., the sky was clear, and there was a slight breeze.

Prior to these recent mass strandings and observations at sea, small numbers of *P. planipes* have been seen in Monterey Bay for the last three or four years.

INFLUX ASSOCIATED WITH INCREASED TEMPERATURE AND NORTHERLY-MOVING CURRENT

Reference has already been made to the first reported observation of *P. planipes* at Monterey in great numbers. Hubbs (1948) has gathered together some very compelling data, physical (increase in mean atmospheric temperatures) as well as biological (more northward distribution of warmer water species), indicating the crabs brought ashore in 1859 appeared during a warm-water phase. The recent sea temperature observations in Monterey Bay, made available through the CCOFI program (California Cooperative Oceanic Fisheries Investigations), indicate quite clearly a general trend toward warmer conditions since 1955 (Table 1). This warm period was especially evident in 1957, and was observed over the entire range covered by the CCOFI survey.

Coupled with this increase in the sea temperature is the recent occurrence around Monterey of a typically more southern fish fauna. Just to briefly list a few, the following have been observed rather

TABLE 1

Mean Temperatures, Centigrade Degrees, for Surface and 15 Meters of Depth from Six Stations in Monterey Bay for the Warmest Month of the Year, 1954-1959

Year	Surface		15 meters below surface	
	Mean temperature	Warmest month	Mean temperature	Warmest month
1954	13.91	October	12.5	November
1955	13.16	October	11.9	October
1956	14.90	October	13.1	October
1957	16.45	October	15.4	October
1958	16.05	August	14.15	October
1959	15.51	October	13.74	October

commonly in the bay since 1957: kelp bass *(Paralabrax clathratus)*, California grunion *(Leuresthes tenuis)*, halfmoon *(Medialuna californiensis)*, Pacific bonito *(Sarda chiliensis)*, white seabass *(Cynoscion nobilis)* and opaleye *(Girella nigricans)*.

According to Skogsberg (1936), a wind-driven mass of surface water frequently flows northward along the coast during the months of December, January and February. This stratum of water is commonly referred to as the Davidson Current, and may well have facilitated the movement of these crabs into the Monterey area from further south. It is also possible that the stranding observation in March of 1859 occurred during the Davidson Current period. Carl Boyd (personal communication) has noted that the maximum abundance of the red crab is centered off the coast along southern Baja California, Mexico. Perhaps the recent warming of the sea permitted *P. planipes* to extend its range to the north and then finally to be carried into Monterey Bay via the Davidson Current.

NOTES ON BIOLOGY

P. planipes is an anomuran decapod of the family Galatheidae. Apart from the lobsters, the anomuran crustacea, including also the hermit and sand crabs, possess a pair of antennae external to the eyes and usually the fifth pair of legs is reduced in size. According to W. L. Schmitt it can most easily be distinguished from the other members of the California Galatheidae in that the sides of the carapace are plainly visible from above (Figure 1). The photograph, which is of a crab taken earlier than those sampled in January, shows a pencil pointing to the larger of two scallops *(Chlamys latiaurata)*, each of which is attached to a cheliped. Approximately 1.5 percent of the specimens examined carried from one to two of these bivalves. This would appear to be a good means of dispersal for *C. latiaurata*, providing the exuvia were cast off in a favorable habitat.

The lengths of 150 individuals of each sex were measured from the tip of the rostrum to the posterior border of the tail fan. The size range was 55 to 70 mm., with the mean 62.3 ± 0.16 mm. A chi square test showed no significant difference in the sizes of the sexes ($P > 0.05$).

On examining the specimens washed ashore it soon became apparent that the sexes could be readily distinguished. The males, as contrasted with the females, possessed short, red hairs which were more numerous on the chelipeds, the tail fan and especially the ventral aspect of the thorax. Only four pairs of pleopods were evident in the females. There were five pairs of abdominal appendages in the males, but the first two are modified in a direction away from the usual paddle-like form, and perhaps are involved in a copulatory function. These two pairs of appendages were rather slender and extensible.

Of 853 specimens sexed, 213 were females—giving a ratio of one female for every three males. Seventy-seven percent of the females were gravid, many in an advanced state.

The red crab, besides its importance as food for some of the larger pelagic fishes, such as yellowfin tuna and skipjack (Schaefer, 1959), is preyed upon extensively by benthic as well as inshore forms, when

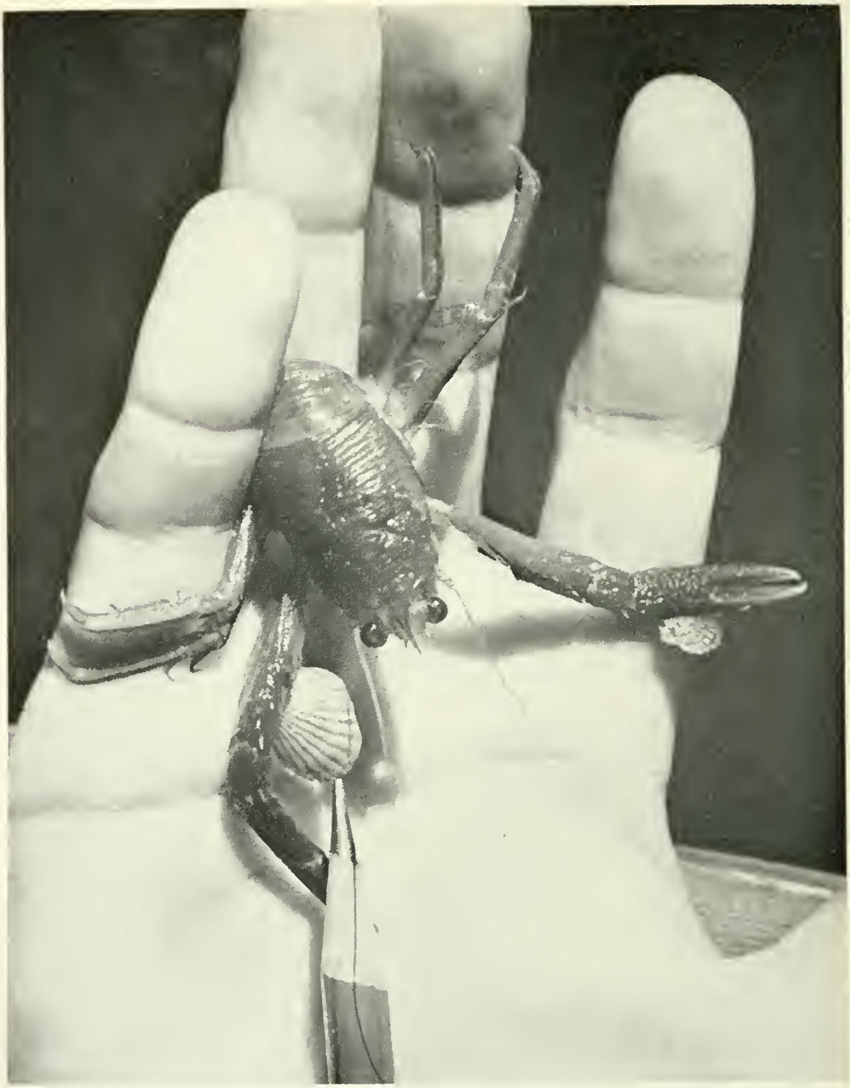

FIGURE 1. Red crab with pencil pointing to scallop on cheliped.
Photograph by Dennis Rowedder, November 1959.

on occasion it approaches more closely to the coast. Stomach analyses have shown that at least six species of rockfishes have fed on them. These are *Sebastodes vexillaris*, *S. miniatus*, *S. rosaceus*, *S. paucispinis*, *S. chlorostictus* and *S. serranoides*. The lingcod, *Ophiodon elongatus*, was also found to have eaten this crustacean. One individual of the red-breasted merganser, *Mergus serrator*, was seen gulping down a red crab in the surf line. During the period of the Monterey invasion, many of the littoral rocky regions frequented by shore birds took on a measly appearance—due to the indigestible, scarlet-colored exuvia left in the

faeces by the birds. This was particularly noticeable in one area frequented by Heermann's gulls, *Larus heermanni*, and California gulls, *L. californicus*, in front of the Hopkins Marine Station.

ACKNOWLEDGMENTS

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THE EXTERNAL MORPHOLOGY OF THE FIRST ZOEAL STAGES OF THE CRABS, *CANCER MAGISTER* DANA, *CANCER ANTENNARIUS* STIMPSON, AND *CANCER ANTHONYI* RATHBUN[1]

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INTRODUCTION

In September 1958, the writer accompanied marine biologists of the California Department of Fish and Game on the research vessel, *N. B. Scofield* to acquaint himself with crab collection techniques used on that vessel. After the crab (*Cancer magister*) season opened in 1958, arrangements were made to accompany Mr. Vern Gingrich on his commercial crab boat, *Merfico IV,* to collect female crabs bearing egg masses. Consequently several such trips were made during the course of the egg bearing season and several samples of crabs (*Cancer* spp.) were obtained. A trip was taken to Scripps Institution of Oceanography at La Jolla, California to consult with Dr. Beatrice M. Sweeney on growing minute plants and animals as possible food for the larvae. Several samples were obtained and transported back to the Pacific Marine Station at Dillon Beach, California for cultivation. An excursion was also made to Eureka and the Oregon border hoping to collect additional specimens.

A search of the literature showed that no papers dealing with the zoea of local *Cancer* crabs were available. Literature on the northern Pacific brachyuran zoea is slight. The prominent papers are those of Aikawa (1927, 1928, 1929, 1933, 1937). These treat a variety of genera and offer useful information for the determination of family characteristics but do not identfy to species any member of the genus *Cancer*. A single paper (Hart 1935) covers some of the Brachyura of the northeastern Pacific but again no member of the genus under consideration is included.

MATERIALS AND METHODS

Where the time required to transport specimens to the laboratory was shorter than two hours, the berried females were placed in a lug box, covered with wet burlap, and kept out of the direct sun. Sea water was poured intermittently over the box to keep them moist and cool

[1] Submitted for publication March, 1960. This study is a contribution of the Pacific Marine Station of The College of The Pacific prepared by service agreement with the California Department of Fish and Game. It is the first report on larval forms of *Cancer* crabs of the West Coast. Only through such research is it possible to identify and study the very young of such economically important species as the market crab. A determination of the success or failure of year classes would permit harvest of the resource at its greatest potential.

during transport. When more than two hours were needed it was found advisable to employ additional measures. Lochhead and Newcombe (1942) had found that eggs of the eastern blue crab, *Callinectes sapidus*, removed from the females and placed in jars could be kept without water for up to 42 hours if under refrigeration. The eggs of *Cancer* species were removed from the females, placed in labeled jars and conveyed in a thermos of cracked ice. This worked well for eggs further than five days from hatching, but for those closer to hatching there was an increase in mortality and imperfectly formed larvae apparently resulted. As a check on this, eggs two to three days from hatching were removed from a female and divided into two groups. One group was placed in a tray and the other into a container and refrigerated for 15 hours. The second group was then placed in a tray and allowed to hatch. In the first sample the eggs hatched normally in two to three days. Hatching among the refrigerated eggs was delayed one or two days and most of the individuals that did hatch emerged in the prezoeal stage. None of this second group survived more than a few days. There was also a marked increased in the number of unhatched eggs in the second tray. It is possible that there is an increased need for fluid transfer through the egg membrane in the last few days before hatching.

Young eggs, two or more weeks from hatching, are bright yellow-orange in color. As hatching nears, the color changes from orange to brick red to tan. When the eggs are a few days from hatching it is possible to discern heart movement, the eyes, and chromatophores.

Removal of the Eggs From the Female

The egg-bearing pleopods of the female were removed with scissors. Care was taken to prevent blood, if any, from coming in contact with the eggs as this is said to prevent normal hatching (Lochhead and Newcombe 1942). The clusters of eggs were washed in fresh filtered sea water to reduce the number of small animals and detritus usually found in association with them. The simplest method of separating the eggs from the clusters involved cutting the cluster into thin slices with a pair of scissors. The free eggs were then washed off into the incubation trays. This destroyed a few individuals but was faster than sorting the individual strands of eggs. The trays employed were enameled metal 19 by 30 by 6 centimeters.

Maintenance of the Trays

Sea water used for the incubation trays was, when possible, collected from the general area where the females were taken. In transporting it to the station, plastic carboys were used to prevent possible metallic contamination. Prior to use, the water was filtered through cotton to remove large planktonic material. This precaution eliminated the possibility of zoea of unknown origin from entering and causing confusion. The water was placed in the trays to a depth of three to five centimeters. Every second or third day it was decanted and replaced. Failure to do this resulted in a loss of eggs, possibly through the action of small ciliated protozoans. The protozoans grew rapidly under the conditions in the trays and clustered around the eggs, apparently finding food

there. If this condition continued, the eggs either failed to hatch or hatched in the imperfect or prezoeal stage and soon died. These protozoans were found in considerable numbers in the berry of all the female crabs examined and are apparently a common part of the berry community. A growth of unidentified organisms also was noted in the unchanged trays.

Temperature control remained a constant problem through the course of the investigations. No facilities for rigid temperature control were available which probably accounted for some of the fatalities encountered during the experiments. An unheated, well-ventilated, cool room in the laboratory building was set aside for the project. This worked well during the winter, but in the spring, trays with viable larvae were placed in a soft drink cooler to maintain a sufficiently low temperature.

Care of the Larvae

Upon hatching the zoea were transferred to other trays to reduce possible crowding and contamination from eggs that failed to hatch. The positively phototrophic zoea were collected by placing a light at one end of the tray and covering the remainder with an opaque card. After a few minutes the zoea were concentrated in the lighted end of the tray and could be easily gathered with a pipette. This also presented a means of roughly separating the prezoeal from the first zoeal stages. The prezoea were not as quick to respond and as a result the true first zoea composed the majority of individuals collected in this way.

The advent of the swimming zoea brought to the fore the major problem of locating a suitable food supply. As yet their exact food requirements remain unknown. Several types of food were tried: a diatom culture was started using Miguels Solution (Galtsoff, 1937); plankton hauls were taken and sorted to remove possible competitors; and, stock cultures of diatoms, small protozoans, and dinoflagellates were obtained during a visit to Scripps Institution of Oceanography and cultivated on a nutrient medium formulated by Dr. Beatrice M. Sweeney, but none of these was successful. Recently the zoea of the eastern blue crab have, for the first time, been reared through all larval stages (Costlow 1959). They were fed the eggs of *Arbacia, Artemia* nauplii and beef liver.

Preservation and Mounting

A segment of the population from each tray was examined alive and then preserved. Several preserving fluids were employed. The principal fluid utilized a mixture of 50 parts Karo syrup, 5 parts formalin and 45 parts water. The specimens were placed directly into this solution either alive or freshly killed. A tube was partially filled with the preservative and a drop of water containing the specimen placed on top. The specimen slowly settled into the preservative. This preservative kept them flexible and had the additional advantage of not disrupting the chromatophores in the zoea. The solution was useful in making temporary mounts where movement of the specimen was desirable but the fluid consistency of concentrated Karo lessened its desirability as a permanent mounting medium. Also the formalin eventually evaporated and bacterial growth became possible. This situation was eliminated

by modifying the formula slightly: replacing the formalin with a few crystals of thymol.

Seventy percent alcohol combined with an equal quantity of glycerine was found suitable as a preservative. The glycerine kept the zoea flexible and reduced the danger of drying through alcohol evaporation. The material so preserved was either taken through a series of alcohols and mounted in balsam or mounted directly in euparal from 70 percent alcohol. This latter method reduced the possibility of losing the small mouth parts while fluids were being changed. A small drop of the mounting medium was placed over the part to be mounted and allowed to dry for two or three days. After that time more material was applied and a cover slip placed over the object. This technique assured placement of the specimen in any desired location or position on the slide.

It was often desirable to manipulate individuals to facilitate study so whole specimens were kept in labeled vials rather than being mounted on slides.

Dissection Methods

In determining specific characters it was necessary to dissect out the various appendages. Because of the size of the organisms this was best accomplished under a binocular dissecting microscope. A deep-well slide was a convenient container for the specimen during dissection. This had sufficient depth to keep the subject covered with fluid but was small enough to prevent the loss or misplacement of the structures after their removal. Fine insect pins, held in pin vises, were used as dissecting needles with considerable success.

Transfers of structures, from the deep-well slide to other slides, was made with a pipette connected by a length of rubber tubing to a hypodermic syringe. This arrangement gave more freedom of movement and control of volume than a conventional dropper.

In making dissections it was found advisable to note orientation of structures so as not to confuse unfamiliar parts.

Drawing Methods and Materials

All drawings were made with the aid of a camera lucida. They were done on heavy grade drawing paper first with a number six pencil and then in India-ink with a Rapido-Graph pen.

CHARACTERS COMMON TO THE VARIOUS SPECIES OF *CANCER* IN THE FIRST ZOEAL STAGE

A dorsal and two lateral carapacial spines are present. The dorsal spine is 0.86 to 0.96 mm long, tapers to a point and curves posteriorly (Figure 1). The lateral spines, 0.22 to 0.29 mm, extend from opposite sides of the carapace. A rostrum measuring 0.51 to 0.80 mm extends downward between the unstalked eyes.

The abdomen, composed of five segments, terminates at the base of the telson. The second abdominal segment bears a pair of centro-lateral spinous projections (Figure 2). The postero-lateral border of each abdominal segment extends in a slight projection caudally to overlap the anterior border of the segment behind it (Figure 1). The telson is bifurcate. Each furca bears three setae on the inner side and a spur-like spine on the inner ramus.

In living and freshly preserved material the following five chromatophores were observed: mandibular, abdominal, precardiac, carapacial and postcardiac (Figures 1 and 2). The names used in identification of these chromatophores follow Aikawa (1929).

The first antenna is 0.014 mm in length and bears three unequal flagellum-like hairs on the distal end (Figure 6). The biramous second antenna (Figure 6) is 0.42 mm long, and the exopodite has short hook-like setae on the distal half of its length. The short endopodite has two unequal terminal setae. The mandible is small with an irregular cutting edge (Figure 5). The first maxilla has a single segmented endopodite (Figure 7), the number of setae varying in a definite pattern from species to species. The basal segment bears a single seta which appears to be constant in position at least in the individuals studied. The basal and coxal endites of the protopodite have five and six setae respectively in the first zoeal stage. This number probably varies from molt to molt (Aikawa 1937, Costlow 1959). The second maxilla has a slightly bifurcated endopodite (Figure 10) the setal arrangement of which is again specific (Aikawa 1937). The number of setae on the slightly bifurcated basal and coxal segments were consistent from species to species but the probable addition of setae from one molt to the next makes them undesirable as species characteristics (Aikawa 1937). The first maxilliped is bifurcate; the endopodite of five segments has a setal arrangement from base to tip of three-two-one-two-five in the first zoeal stage. The number and arrangement of the setae varies from stage to stage (Aikawa 1937) but is constant within the stage. The segmented exopodite bears four natatory hairs in the first larval stage (Figure 3). The second maxilliped has an endopodite of three segments with a setal arrangement of one-one-five and the exopodite bears four natatory setae (Figure 4). The number of natatory setae will vary in a constant pattern from one zoeal stage to the next (Aikawa 1937).

CHARACTERS OF THE SPECIES STUDIED

Cancer magister Dana

This description is based on the examination of 35 individuals from six separate female crabs. The distal segment of the endopodite of the first maxilla bears six setae (Figure 7) arranged in three pairs of two each. The distal pair are unequal in length and the proximal pair are sub-terminal. The endopodite of the second maxilla (Figure 10) has seven setae arranged from distal to proximal in a four and three pattern.

Cancer antennarius Stimpson

Thirty-two individuals from three females showed the endopodite of the first maxilla to have four setae terminal on the distal segment (Figure 8). The second maxilla had an arrangement of three distal and three proximal setae totaling six on the endopodite (Figure 11).

Cancer anthonyi Rathbun

Based upon 30 individuals, the distal segment of the endopodite of the first maxilla bears five setae in an arrangement of one-two-two from the distal to the proximal region of the segment (Figure 9). The bifur-

PLATE 1

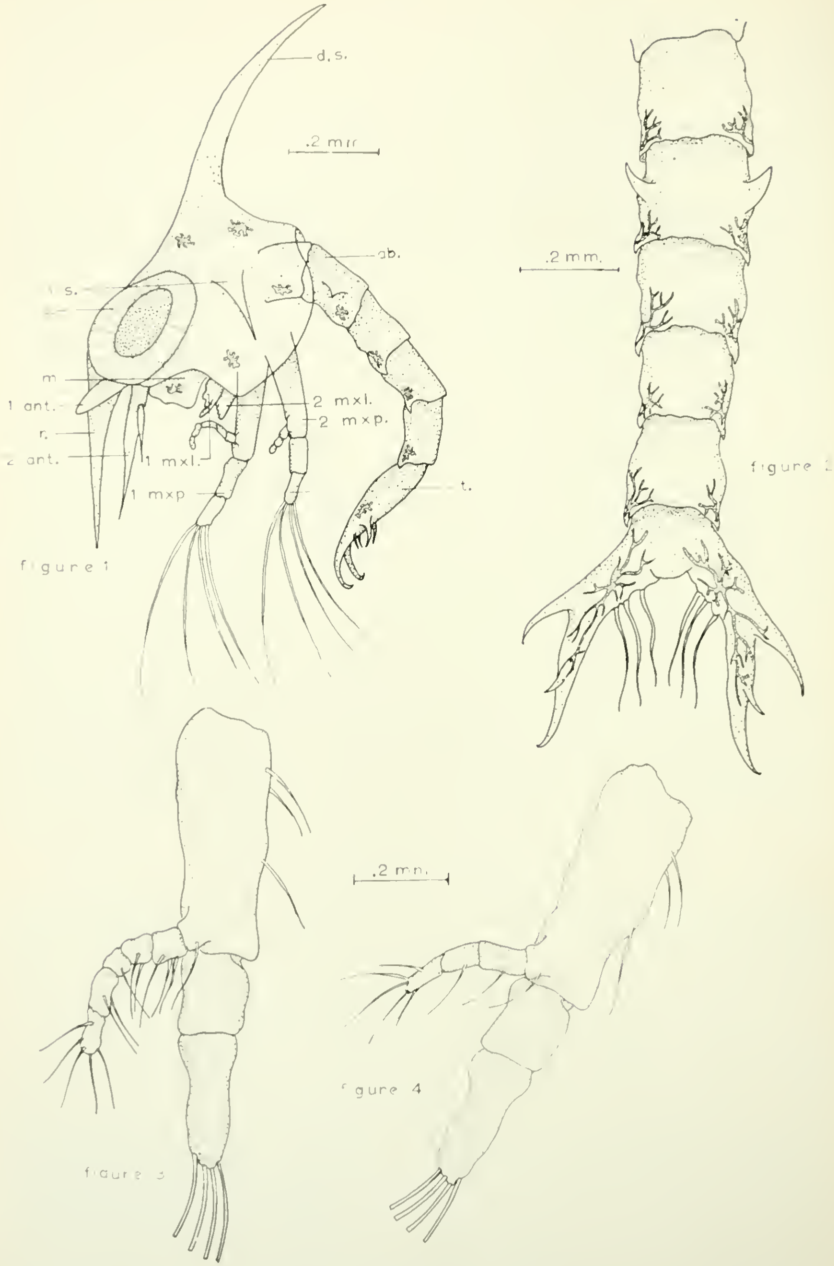

FIGURE 1. Zoea of the genus Cancer

ab.—abdomen
1 ant.—first antenna
2 ant.—second antenna
d.s.—dorsal spine
e.—eye
l.s.—lateral spine
m.—mandible
1 mxl.—first maxilla
2 mxl.—second maxilla
1 mxp.—first maxilliped
2 mxp.—second maxilliped
r.—rostrum
t.—telson

FIGURE 2. Abdomen and telson of first zoeal stage.
FIGURE 3. First maxilliped of first zoeal stage.
FIGURE 4. Second maxilliped.

PLATE 2

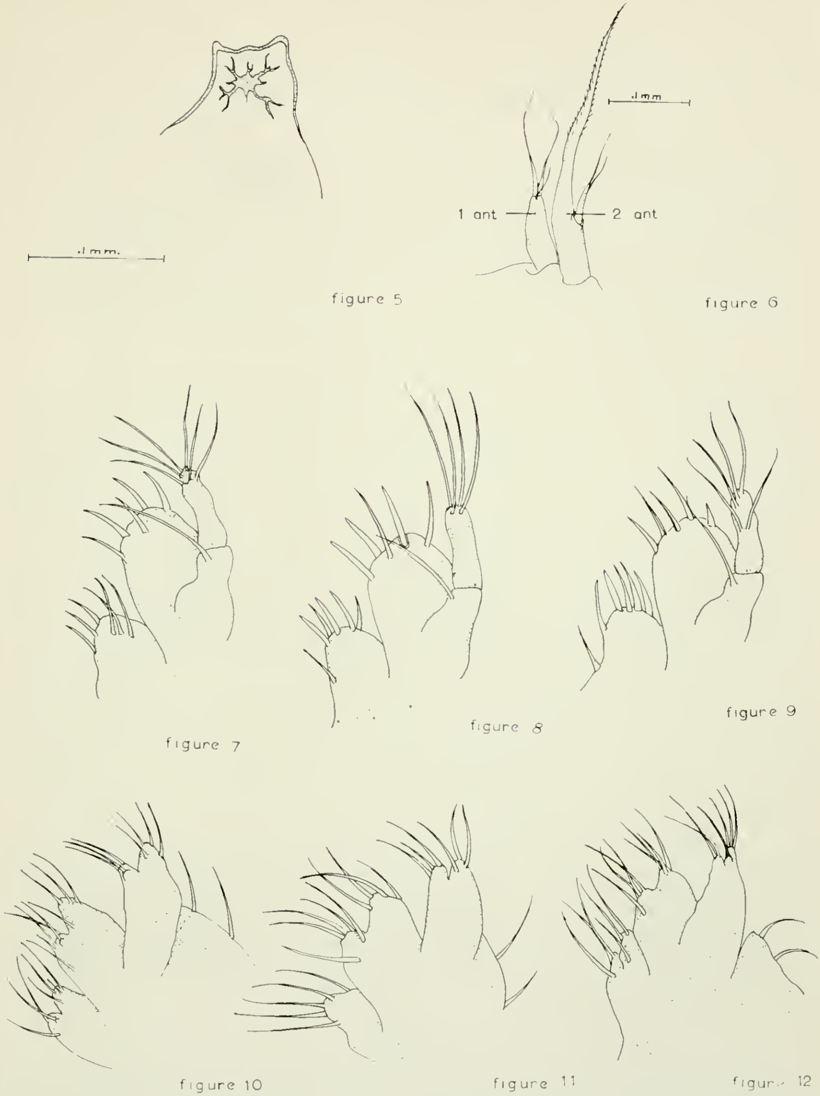

FIGURE 5. Mandible of first zoea of *Cancer* spp.
FIGURE 6. First and second antennae of *Cancer* spp.
FIGURE 7. First maxilla of *Cancer magister*
FIGURE 8. First maxilla of *Cancer antennarius*
FIGURE 9. First maxilla of *C. anthonyi*
FIGURE 10. Second maxilla of *C. magister*
FIGURE 11. Second maxilla of *C. antennarius*
FIGURE 12. Second maxilla of *C. anthonyi*

cate endopodite of the second maxilla has six setae arranged four and two, distal and proximal respectively (Figure 12).

KEY TO THE ZOEA DESCRIBED IN THIS PAPER

1. Distal segment of endopodite of first maxilla with 6 setae (Figure 7); endopodite of second with 7 arranged in a 4 and 3 pattern (Figure 10) *Cancer magister*
1. Distal segment of endopodite of first maxilla with other than 6 setae and endopodite of second maxilla with other than 7 ______ 2
2. Distal segment of endopodite of first maxilla with 4 setae (Figure 8); endopodite of second with 6 arranged in a 3 and 3 configuration (Figure 11) *Cancer antennarius*
2. Distal segment of endopodite of first maxilla with 5 setae (Figure 9); endopodite of second with 6 arranged 4 and 2 (Figure 12) ___ *Cancer anthonyi*

DISCUSSION

This paper is the first in a proposed project to formulate a key for the zoeal stages of *Cancer* crabs found on the Pacific Coast of the United States. In addition to the species included in this paper, six others have been reported (Schmitt 1921): *Cancer productus* Randall, *Cancer amphioetus* Rathbun, *Cancer gracilis* Dana, *Cancer gibbosulus* Dana, *Cancer jordani* Rathbun and *Cancer oregonensis* Dana.

A few berried females of *Cancer productus* were obtained late in the winter and set out in trays. However the advent of warm spring weather in 1959, possibly combined with other undetermined factors caused premature or imperfect hatching of almost all the zoea. Only two specimens were found in what was apparently the true first zoeal stage. No description is given of these since the number was considered too small to be reliable and since examination of them showed an apparent variance in setal structure. It is felt that more individuals should be examined to determine whether the variance is significant or the result of faulty procedure.

While removing the eggs from the female crabs many animals were found living in the berry. Some apparently are commensals, depending on the developing eggs as a source of food. In addition to the ciliated protozoans mentioned previously, about a dozen animals from at least three phyla were observed. A study should be conducted on these animals to determine their inter-relationships and possible effect on the number of larvae hatched.

SUMMARY

The first zoeal stages of three species of *Cancer* are described in detail and a key is given for their identification. Measurements and figures of the zoea are given, as are notes on the culture techniques used.

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NOTE

WATERFOWL BOTULISM OUTBREAK IN SAN JACINTO VALLEY, RIVERSIDE COUNTY, CALIFORNIA

Botulism of epidemic proportions developed in Tulare Lake and many other waterfowl areas in Central and Southern California in the fall of 1958. This report summarizes field observations of the disease at the H C & S Ranch near Lakeview, Riverside County, California during the fall and winter of 1958-1959.

The H C & S Ranch contains about 160 acres of shallow, artificially flooded ponds lying in the alkaline lake bottom of the former San Jacinto Lake. The ponds are partially flooded during the summer for cultivation of water grass (*Echinochloa crusgalli*) and alkali bullrush (*Scirpus paludosus*) and are almost entirely flooded from October through February for the hunting season.

Sick and dead ducks became evident the first week of September 1958 and more were found continually until March 1959. From September until January dead ducks were gathered up every day or two and buried. A count on September 28, 1958 was quite typical and showed 30 pintail (*Anas acuta*), three green-winged teal (*Anas carolinensis*) and one mallard (*Anas platyrhynchos*). The largest number of dead birds gathered was on November 20, 1958 when a count of 103 was made, although the ponds were not completely searched. It is estimated that 1,800 to 2, 000 ducks were gathered up and buried during the four and one-half month period. This approximates the recorded hunting kill of 2,110 ducks for the same season on these ponds.

An unusually hot and dry fall probably played a part in this outbreak of botulism. Even in December the temperature was above 80 degrees for a number of days. However, in November when the outbreak of disease was most evident the water was not warm in that ice formed on the ponds during several nights. This suggests that dangerous amounts of toxin were present in the ponds at times when the botulism organism was presumably not growing, since its reproduction is associated with warm water temperatures. Bonventre and Kemp (1959) reported that at 10 degrees C. or below, metabolic activity of *C. botulinum* type A was not detectable and that between 10 and 18 degrees C. there was partial growth and toxin synthesis.

Many species of birds were found dead or sick with the typical symptoms of muscular weakness and diarrhea on or about the ponds. Pintail, green-winged teal, mallard and widgeon (*Mareca americana*) were the most commonly afflicted ducks and about 75 percent of these were pintail. Other species included the shoveller (*Spatula clypeata*), cinnamon teal (*Anas cyanoptera*), gadwall (*Anas streperus*), avocet (*Recurvirostra americana*), sora (*Porzana carolina*), red-winged blackbird (*Agelaius phoeniceus*) and pheasant (*Phasianus colchicus*). Con-

spicuously absent from this list is the coot (*Fulica americana*) although several hundred were present during the entire period of observation.

There were some coots killed or crippled by hunters, but none were found before or after the hunting season where it appeared that they had succumbed to botulism. This might be explained by their food habits. Their stomachs contained mostly green vegetable matter, in contrast to the ducks whose stomachs contained predominantly water grass seed and alkali bullrush seed which had been sifted out of the water and mud of the shallower ponds.

No previous outbreaks had been observed in this vicinity in the preceding four years of regular waterfowl observation. However, Frank Motte, owner of several small duck clubs in this area, stated that there was a conspicuous outbreak about eight years ago.

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BOOK REVIEWS

Manual of Game Investigational Techniques

Edited by Henry S. Mosby; The Wildlife Society, c/o Virginia Coop. Wildl. Res. Unit, Dept. of Forestry and Wildlife, Blacksburg, Virginia, 1960; approx. 360 pp., illus., $4.50.

The Wildlife Techniques Committee of the Wildlife Society is responsible for the preparation of this manual, and it is released under the sponsorship of the Wildlife Society. In the words of Dr. Mosby, the committee chairman and editor, the purpose is to report the best procedures as currently developed and understood. No effort is made to catalogue all techniques, or to establish standard techniques. The format and page numbering will facilitate revisions in future editions, since it is realized that techniques are continually being improved or replaced by better ones.

The manual is divided into 17 sections, each with its own pagination as follows: Techniques and the Game Investigator, Record Keeping by Means of Field Notes and by Photography, Reconnaissance Mapping, Evaluation of Habitat, Estimating the Numbers of Game Populations, Criteria of Sex and Age, Animal Population Analysis, Preserving Biological Material, Post Mortem Examinations, Capturing and Marking Wild Animals, Measuring Hunting and Other Mortality, Control of Nuisance Wildlife, Food Habits Procedures, Presentation of Numerical Data, Using Wildlife Literature, Project Planning, Reporting Research Results.

The method of presentation draws on examples which illustrate the fundamentals upon which the several techniques are based.

Specialists are certain to find omissions and may choose to quarrel with the authors on their choice or presentation of material. In a work of this nature, such pitfalls are unavoidable. In general, every wildlife worker should find this manual to be of great value.

The volume of literature currently being produced in the wildlife field is immense. A specialist is hard-put to keep up with developments in his particular area while the effort required to forage through the entire galaxy of wildlife literature is staggering. It is only through compilations and manuals, such as this, that a person can hope to dig out information and techniques with any degree of speed and efficiency.

I feel that every wildlife worker will profit by owning this manual. The cost is ridiculously low for this day and age. I sincerely urge that each of you in the business add this to your personal library.—*Fred L. Jones, California Department of Fish and Game.*

Northern Fishes

By Samuel Eddy and Thaddeus Surber; Charles T. Branford Company, Newton Centre, Massachusetts, revised edition 1960; xii + 276 pp., illus. $5.

"Northern Fishes", first printed in 1943, has been revised and reprinted in an attractive format. The introductory sections have been expanded and brought up to date. They discuss such things as angling methods and various technical aspects of fisheries management for the layman's articles.

The main body of the book, dealing with identification of some 150 species of fishes in the northern Mississippi drainage and with the characteristics of these fishes, is little changed from the original edition although some of the keys have been improved. The black-and-white illustrations of 86 species are generally attractive and adequate. In most cases, the plates from the first edition were used again, however, the printer did a much better job with them in the new edition. Unfortunately, this is not the case with the color plates which are poor.—*Alex Calhoun, California Department of Fish and Game.*

The Sea off Southern California, a Modern Habitat of Petroleum

By K. O. Emery; John Wiley & Sons, Inc., New York, 1960; xi + 366 pp., 248 figs., 1 map. $12.50

To the uninformed, a hasty glance at the title leaves a feeling the subject could have been thoroughly covered in a volume half this size. However, a critical perusal of the table of contents, chronological inspection of a dozen or so of the carefully selected illustrations and ten minutes of attentive reading in the text will dispel utterly any such preconceived fears. In fact, a complete reversal of thinking is likely to occur in which one wonders how such a vast undertaking could have been accomplished in so few pages.

The publishers could not have chosen a more competent or well-versed authority to compile this volume. Dr. Emery's knowledge of the area—its composition, structure, geology and natural history—has been obtained primarily from first-hand, on-the-spot studies. This reviewer recalls a time several years ago when, simply by examining a number of lots of rounded, beach-worn cobbles removed from sealion stomachs, Dr. Emery correctly identified the specific localities (islands, beaches, etc.) where the sealions had been collected.

To present a clearer picture of the book's scope, a listing of the chapter headings seems in order. Chronologically these are: *Physiography, Lithology, Structure, Water, Life, Sediments,* and *Economic Aspects.* Within the chapter on physiography are nine subsections dealing with exploration, general description, coasts, shelves and bank tops, basin and trough slopes, submarine canyons, basins and troughs, continental slope, and abyssal sea floor. Six subtitles are included under the chapter on life—not one of the strongest sections of the book.

The 22 ages of references (several hundred entries), the author index and the subject index are extremely helpful for searching out specific details or for finding a more complete coverage of a particular subject. A map of the southern California coast (scale 1: 500,000; contour interval 300 feet) showing the relation of land and submarine topography is tucked under a flap on the inside of the back cover.

A cursory examination of the entire volume and careful reading of numerous select sections revealed several interesting conclusions: 1, stressing petroleum in the title is misleading and could cause a multitude of workers, interested individuals and students to overlook the book, even though it contains just the type of information they would want; 2, the author's style is such that no one, regardless of background, should have difficulty understanding what he has written; and 3, by having covered (completely but not exhaustively) such an expanse of material in so few pages, the author has produced one of the most thought-provoking volumes I have encountered in years. Regrettably, the purchase price will restrict ownership of this highly desirable item.—*John E. Fitch, California Department of Fish and Game.*

List of the Marine Fishes of Canada

By D. E. McAllister. National Museum of Canada, Ottawa. Bull. 168, iv + 76p., 1960. $1.25.

All species of fish recorded from the brackish and marine waters (three oceans) of Canada have been included. A hasty check revealed 6 lampreys and hagfish, 38 sharks and rays, 4 chimaerids and some 487 bony fishes. These are primarily fishes of the continental shelf and offshore fishing banks, however, a few deep-sea items also have been listed. The classification follows Berg, with some modifications.

The scientific names are arranged alphabetically within each family or subfamily. Each is followed by the author and date of publication. A common name, if any, is listed next followed by an indication of general oceanic distribution. At least one recent reference is supplied for each species and if a taxonomic or nomenclatorial problem rears its ugly head, the situation is adequately discussed.

The species list takes up 50 pages and follows a brief—3-page—introductory section. Ten pages of references and a 13-page index to common and scientific names complete the work.

This publication is extremely useful and should be possessed by everyone even remotely interested in ichthyology, marine fishes or fishing.—*John E. Fitch, California Department of Fish and Game.*

A List of Common and Scientific Names of Fishes from the United States and Canada (second edition)

American Fisheries Society. Spl. Publ. No. 2. Waverly Press Inc., Baltimore. 102 p. 1960. $1 paper cover, $2 cloth cover.

In a five-page introductory section the AFS seven-man committee on names of fishes (Reeve M. Bailey, chairman):

1. explains the area of coverage (those species known from the fresh waters of continental U.S. and Canada and those marine species inhabiting contiguous shore waters on or above the continental shelf, to a depth of 100 fathoms. Deepsea fishes are excluded unless they appear also within the 100-fathom isobath);
2. discusses the need for common names;
3. lists the 19 principles used as criteria and guides for selecting or discarding common names;
4. tells about the plan of the list;
5. calls attention to the indices and their usage;
6. acknowledges considerable assistance.

On each page, common names are arrayed along the left margin. Centrally, a letter or letters (A, P or F) provides a general guide to distribution. Along the right margin is the scientific name and authority. I am taking the committee's word that there are 1,892 entries.

Within each family the scientific names are arranged in alphabetical sequence. The list of names runs from page 6 to 50. An index to common names (page 51 to 75) and another to scientific names (page 76 to 102) complete the volume.

Most "unofficial" vernaculars appear within the common-name index, rendering more facile the chore of searching out a scientific name when only a local misnomer is at hand.

In perusing the list it soon becomes obvious the committee was more inclined toward lumping than splitting—a praiseworthy trait. Equally as obvious is the fact that many of the official vernaculars represent a majority vote of the committee and thus their unanimous acceptance by fishermen, fishery workers, processors and other interested parties can not be expected. The list should give a tremendous boast toward unanimity, however.

My one suggestion for the third edition, if such is forthcoming, would be inclusion of the publication date after the name of the authority for each scientific name.

Because the price of this item is so reasonable, each person having a need for it should purchase two copies. By doing so, he can keep one at home and one at the office. Such an arrangement precludes being caught short during hot arguments over fishes and their names, regardless of where they take place.

Orders, accompanied by a remittance payable to the American Fisheries Society, should be addressed to E. A. Seaman, Sect.-Treas., A.F.S., Box 483, McLean, Va.

John E. Fitch, California Department of Fish and Game.

The Marine Fishes of Rhode Island

By Bernard L. Gordon; The Book and Tackle Shop, Watch Hill, Rhode Island, 1960; xi + 136 pp., 77 pl., 1 fig., 5 tabl., $4.

An annotated checklist of the fishes found in the marine environment of Rhode Island and as far inland as the limited of tidal influence. Included are the eastern ends of Fisher's Island Sound and Long Island Sound, Block Island Sound, Rhode Island Sound, and the waters of the continental shelf beyond Block Island.

The fish are grouped in a taxonomic array patterned after Bigelow and Schroeder (*Fishes of the Gulf of Maine*) and Breder (*Field Book of Marine Fishes of the Atlantic Coast*). For each of the 215 species observed or reported in the literature a short paragraph reports occurrence, size, relative abundance, use, and, in many cases, the disposition of specimens. Tables list 40 species not previously reported from Rhode Island waters, 31 not reported for the past 40 years, and 5 the author considers questionable.

The bibliography of 111 references is an excellent starting place for anyone studying fishes of New England.____*E. A. Best, California Department of Fish and Game*

Diagnosis of Veterinary Parasitisms

By J. H. Whitlock; Lea & Febiger, Philadelphia, 1960; 236 pp., 368 illus. on 98 figures. $10.

Dr. Whitlock in his opening statement limits the use of this book to those conversant with the field of specialized parasitology: the veterinary pathologist, practitioner, or student. Unlike other texts that discuss the various parasites of each animal the author considers each parasite in turn and allows the hosts to fall where

they may. But even in this he is inconsistent, e.g. the trematode key merely differentiates the families without reference to host, whereas a similar key is presented of the cestode genera of poultry, and two charts are devoted to those affecting selected mammals. On the other hand there is a profusion of information on the nematodes that is not only replete with reference to the variety of hosts affected but is keyed to the individual species in great detail. A hint of this disparity was acknowledged by Dr. Whitlock in the preface, "It would be especially useful if some platyhelminth specialist could find an objective way of representing his material." It is true that the subject of the nematodes is more extensive than that of the other helminths. However, there is undue emphasis as indicated by the 109 pages that cover the Nematoda, whereas Cestoda are given 15 pages and the Trematoda only five pages.

The protozoologists will not be happy when they read in the introduction "Although traditionally protozoology has been considered a component of Veterinary Parasitology, the line between the bacteria and the protozoa . . . is exceedingly fine or even nonexistent. . . . In the temperate regions of the world protozoology is logically an appendage of bacteriology." This may be classified as a "sin of omission" in a book with the title "Diagnosis of Veterinary Parasitisms."

The first third of the book discusses the field of veterinary entomology with useful albeit sketchy keys to the genera concerned. In the entomology section as with the helminths, the parasites afflicting wildlife are either ignored, mentioned in passing, or discussed in detail only if the hosts can be feral as well as domestic. On the other hand where there is an overlap of species into the field of human parasitology adequate coverage is given by the author.

Dr. Whitlock has taken text from the authorities in the field and his discussions are predominantly composed of quotations from their works. When he relies on his own knowledge and capabilities as an author his style is flowing, easy to follow, and he imparts an interest in what might otherwise have been treated as a dull subject. In the appendix there is a section on "diagnostic problems at the boundary area between veterinary and human parasitology" that is an interesting discourse on the parasitic zoonoses. This is followed by some technical notes that compresses laboratory technics to the point of being reminder notes.

What this book might lack in some definitive keys is compensated by a great profusion of excellent illustrations. The diagrammatic sketches are well done and these are supplemented by photomicrography at its best. As might be expected from the foregoing, the photomicrographs primarily cover the nematodes and assist in keying the arthropods. This volume will be a handy reference book when used in conjunction with other texts.—*Merton N. Rosen, California Department of Fish and Game.*

The Biologists Handbook of Pronunciations

By Edmund C. Jaeger; Charles C. Thomas, Publisher, Springfield, Illinois, 1960; 317 pp.

The need for a book of this type is very apparent when one tries to find the pronunciation of a scientific name in the dictionary. Some are there but many are not. Many words used by biologists are used so infrequently that incorrect pronunciation is quite common, even among learned students.

There are over 9,000 words listed in the book which do not include many commonly used terms and generic names of obvious sound and accentuation. Each specific name included has its original Greek or Latin meaning or English equivalent given.

The six page introduction is a must to mastering the pronunciation, for here is found the key to using this book correctly. Diacritical marks and the sounds of the letters are found inside both the front and back covers of the book for handy reference.

Although the book is not intended to be a dictionary or source book of derivation, the very fact that specific names have a brief meaning after the pronunciation while other words have nothing, leaves the inquiring student a little perplexed and makes the work seem incomplete.

This book should be a handy reference book, especially for teachers and those people who may use scientific terms in their speech.—*Jack L. Hiehle, California Department of Fish and Game.*

The Physiology of Crustacea. Volume I—Metabolism and Growth

Edited by Talbot H. Waterman, Academic Press, Inc., New York, 1960; v + 670 pp., 57 tables, 6 plates, 77 figures. $22.

This book (and its companion, Vol. II, Sense Organs, Integration, and Behavior, soon to be published), is the result of an ambitious project designed to provide a "coherent review of the physiology of Crustacea." Authorities from various parts of the western world expound on the topics of *General Crustacean Biology, Respiration, Circulation and Heart Function, Feeding and Nutrition, Vitamins, Digestion and Metabolism, Osmotic and Ionic Regulation, Excretion, Terrestial Adaptations, Ecology and Metabolism, Sex Determination, Integument and Exoskeleton, Molting and Its Control, Relative Growth, and Autotomy and Regeneration.*

Excellent photographs, drawings, and tables are used throughout the volume. The authors should be complimented on the extensive lists of world-wide references presented at the end of each chapter. Useful author, systematic and subject indexes are also worthy of note.

Although written as a contribution to the field of comparative physiology, the crustacean biologist will find much to hold his interest. It must be pointed out, however, that this book is written for the physiologist and relatively little attention has been given the commercially important species.

The high price of $22 will prevent most biologists from purchasing this book. It should be available in the libraries, however, because of the wealth of material and references it contains.—*James D. Messersmith, California Department of Fish and Game.*

The Biology of Marine Animals

By J. A. Colin Nicol; Interscience Publishers, Inc., New York, 1960; xi + 707 pp., illus., $14.

This is a textbook of comparative physiology of marine animals. The physiological adaptations of marine animals to meet the demands of their environment, whether it is the variable conditions of estuarine and littoral regions or the more stable conditions of the open ocean, is the theme throughout the book.

The introductory chapter gives a brief summary of the marine habitats in which the animals live. Succeeding chapters deal with circulation, respiration, feeding, digestion, excretion, sense organs, effector mechanisms, nervous system, pigments and color, color changes, luminescence, associations, and skeletons, shelters and special defenses of the subject animals. Those chapters are usually divided into phyla for discussion. Extensive references follow each chapter.

In the author's words this book is intended for "undergraduate specializing in marine zoology and young biologists making excursions to the sea for the purpose of studying . . . and a knowledge of comparative morphology and general biology has been presumed on the part of the reader." These are definite prerequisites for the full utilization of the wealth of information compiled in this work.—*E. A. Best, California Department of Fish and Game.*

Kingdom of the Octopus

By Frank W. Lane; Sheridan House, New York, 1960; xx + 300 pp., frontispiece and 4 plates in color, 48 plates in black and white, 13 figs., $7.50.

The octopus is a fascinating and mysterious denizen of the deep whose habits have been the subject of many colorful stories, both fact and fiction, since the time of Aristotle. The author has sifted the facts from an immense number of publications, observations, travel diaries, ship logs and stories and condensed them in readable fashion. Liberal use of color and black and white plates add to the general interest of the book. All scientific terms have been translated into common terms familiar to everyone.

The text has not been limited to the octopus but has space in each chapter devoted to the squid and cuttlefish plus some observations on the pearly nautilus. Chapter titles cover the standard life history functions plus fishing, economics, dangers and kraken. In the chapter on economics, reference is made to the drying of squid in California as the most important method of preservation. While this was true historically, today canning has completely replaced drying of squid.

Included in the appendices are a family tree, a systematic list of all cephalopods mentioned in the text, list of common and scientific names used, glossary of terms, and an extensive bibliography for each chapter.

Mr. Lane should be commended for his style of writing, which extracts the meat from published articles and condenses it into a neat package easily swallowed by fishermen, skindivers, or the interested public. The chapters on dangers and kraken are so interesting it is difficult to put the book down until finished.—*E. A. Best, California Department of Fish and Game.*

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STATE OF CALIFORNIA

FISH AND GAME COMMISSION

Notice is hereby given that the Fish and Game Commission shall meet on April 7, 1961, at 9.30 a.m., in the California State Building, First and Broadway, Los Angeles, California, to receive recommendations from its own officers and employees, from the Department of Fish and Game and other public agencies, from organizations of private citizens, and from any interested person as to what, if any, orders should be made relating to birds or mammals, or any species or variety thereof, in accordance with Section 206 of the Fish and Game Code.

FISH AND GAME COMMISSION
Wm. J. Harp
Assistant to the Commission

Notice is hereby given that the Fish and Game Commission shall meet on May 26, 1961, at 9.30 a.m., in the State Employment Building, 722 Capitol Avenue, Sacramento, California, to hear and consider any objections to its determinations or proposed orders in relation to birds and mammals for the 1961 hunting season, such determinations resulting from hearing held on April 7, 1961, commencing at 9.30 a.m. in the California State Building, Los Angeles. This notice is published in accordance with the provisions of Section 206 of the Fish and Game Code.

FISH AND GAME COMMISSION
Wm. J. Harp
Assistant to the Commission